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A Study of Five Commercial Electric Stoves

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COLLEGE OF AGRICULTURE UNIVERSITY OF NEBRASKA
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FOREWORD

By its very nature this report will appeal only to technical people. To fill the needs of those who are not interested in experimental procedure and technical results but wish only to know how to choose wisely and operate economically an electric stove, a non-technical bulletin is being prepared.

CONTENTS

SUMMARY

Five commercial electric stoves having major variations in types of surface units, in the construction, lining, and insulation of the oven, and in the retail price were studied to determine (1) the efficiency and time of heating of the various surface units, and (2) the merits of differently constructed ovens.

SURFACE UNITS

The efficiency and time of heating for both cold and hot starts for short-time tests of three types of surface units, namely open type, solid cast type, and tubular or ring type solid, were found by heating successively 4, 3, 2, and 1 pounds of distilled water from 72° to 206° F. in various sizes and types of covered and uncovered aluminum and enameled pans. For long-time tests for both cold and hot starts the efficiency was found by heating 4 pounds of distilled water in covered aluminum and enameled pans from 72° F. to the boiling point, after which the water was kept boiling for the remainder of the one-hour test period. Energy was measured with a Sangamo-type H-C watt-hour meter and checked by a potential-current-time product. For all surface-unit tests the potential was kept constant at 220 and 110 volts. The temperature of the water was measured with copper-constantan thermocouples connected to a Leeds & Northrup portable potentiometer. The radiation and convection loss of the various utensils at the boiling point of water was found by using an immersion heater.

Comparative time-of-heating results have been presented in tables. Two efficiencies have been considered, minimum and actual. The minimum efficiency includes as the output only the amount of energy necessary to heat the water through the 134 degrees of temperature change, while the actual efficiency includes as the output the amount of energy necessary to heat the water and pan and also the energy lost by evaporation. For the long-time tests the radiation and convection loss of the utensils at the boiling point of water was also included in the output.

The results of the surface-unit tests indicate the following:

1. Units having a small watt rating are more efficient than units having a large watt rating.
2. The tubular and the ring-type units are the most efficient for general use.
3. The open units of stove E were more efficient than the open units of the other stoves studied.
4. The cone and reflector units are efficient for short-time processes when started cold, but for all other processes they are inefficient when compared with the other open-type units studied.
5. The solid cast units are inefficient for cold starts but for long-time processes they are very efficient.
6. The utensils should have straight side walls, should not be too high, and should be of a size to fit the unit exactly. The cover should make perfect contact with the side walls.
7. For short-time processes either enameled pans or black-bottomed aluminum pans should be used on open and tubular or ring-type units. For all solid cast units, aluminum pans with bottoms making perfect contact with the unit should be used.
8. For all long-time processes aluminum pans should be used on all units.

OVENS

The ovens were rated by determining and comparing, for empty ovens, (1) the time and energy required to preheat, (2) the total heat

loss, (3) the heat loss per square foot, (4) the heat loss when the oven door was opened, (5) the time rate of cooling, (6) the calibration of the thermostat, and (7) the temperature distribution in the oven for various average temperatures.

All average temperatures were measured by five copper-constantan thermocouples connected in parallel in the mid-plane of the oven. Shields were used to protect one set of couples from radiant energy. The temperature distribution in the oven was measured with fifteen copper-constantan couples arranged in three planes with five couples in each plane. For steady-state tests three exterior oven temperatures were also recorded. Energy was measured with the watt-hour meter and checked by a potential-current-time product.

The results for the preheating tests, the heat losses, and the time rate of cooling are shown graphically. Thermostat and heat distribution results are shown in tables. Where a ranking involves time or energy the ovens are ranked in ascending order of the time and energy required.

The results of the oven tests indicate the following:

1. In the order of the time and energy necessary to preheat with all units on HIGH, the ovens ranked in the order D, C, E, A, and B.

2. For total heat loss the ovens ranked B, A, C, E, and D.

3. For the heat loss per square foot the ranking was B, A, E, C, and D.

4. The heat lost when the oven door was opened, was almost the same for ovens B, C, and D for oven air temperatures up to 400° F., with oven A next in order and oven E losing the most heat. For oven air temperatures above 400° F., the ovens ranked C, D, B, A, and E.

5. Oven B cooled most slowly and oven D most rapidly, the order of ranking for all being B, E, A, C, and D.

6. In energy required to preheat and to maintain at a desired temperature for one hour of thermostat operation, oven D was the most economical. For periods of thermostat operation greater than one hour, oven B was the most economical. The remaining ovens ranked C, A, and E for all periods of thermostat operation; oven E used the most energy.

7. Because of the principle of operation, the thermostat on oven B should not be compared with the other thermostats. The calibration of the thermostat of oven E was the most accurate, with that of oven A next. The calibration of the thermostat of oven C was too high at 450° and 500° F. and much too low at 300° and 250° F. The calibration of the thermostat of oven D was fairly accurate at 450°, 500°, 550°, and 600° F., but the average temperatures were much too high at 400°, 350°, 300°, and 250° F. Oven D had the most sensitive thermostat.

8. The temperatures of the oven air at various locations in the oven was found to be sufficiently uniform for practical purposes in all stoves.

A Study of Five Commercial Electric Stoves

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Department of Home Economics

During the last few years, the use of electrical energy for cookery has been increasing in popularity wherever it can be obtained at a favorable price when compared with the cost of other forms of energy. In the past, cost of operation and a popular belief that electric cookery was slow have tended to prevent the general acceptance of electric stoves in spite of the efficiency and convenience they offer.[3]

PURPOSE OF INVESTIGATION

Most of the recent research on electric stoves has been done by manufacturers, and the results are not available to the public. As early as 1915, disinterested institutions began to publish bulletins on electric cooking appliances,[4] but since no complete study comparing various types of electric stoves is

TABLE 1.—*Dimensions*

Stove	Over all: Maximum length	Over all: Maximum width	Over all: Height from floor to top of oven	Over all: Height from floor to top of cooking top	Cooking top: Width	Cooking top: Depth
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
A	44¼	23½	40½	32¾	24¼	22¾
B	42¼	24¼	45¼	33¼	22⅞	24¼
C	38¾	20½	44⅜	33⅞	20¾	20½
D	40	22	42	32	22	22
E	47	25¾	40½	32¼	25¾	25

Ovens

Stove	Interior: Height	Interior: Width	Interior: Depth	Interior: Volume	Exterior: Effective height[1]	Exterior: Width	Exterior: Depth	Exterior: Height of oven top above cooking top
	Inches	*Inches*	*Inches*	*Cu. ft.*	*Inches*	*Inches*	*Inches*	*Inches*
A	14	16	18½	2.40	19	20¼	23½	7⅞
B	14	16	17	2.20	17½	19½	19¼[2]	13
C	14	14	18¼	2.10	18	18	21[2]	10⅜
D	16	14	19	2.46	18¼	16¼	21	11
E	15	16	18	2.50	20½	21½	24	8¼

[1] Portion of sides below bottom of oven not included.
[2] Thickness of oven doors not included.

[1] Formerly instructor in the Department of Physics, University of Nebraska.
[2] Research specialist in Home Economics.
[3] For comparison of efficiency of electric stoves with other types of stoves, see Bulletin No. 3, American Gas Association Inc. Testing Laboratory, Cleveland, Ohio, 1928; Bulletin No. 339, Agr. Exp. Sta., Purdue University, 1930; and "Kitchen Tests of Relative Cost of Natural Gas, Soft Coal, Coal Oil, Gasoline, and Electricity for Cooking", Ohio State University, 1917.
[4] "The Economics of Electric Cooking", P. W. Gumaer, University of Missouri Bulletin, Vol. 16, No. 27, 1915; "Electric Cooking Appliances", R. G. Kloeffler, Kansas State Agricultural College Bulletin, Vol. 1, No. 20, 1917; "Electric Ranges", C. W. Piper, Bulletin No. 2, Engineering Experiment Station, Purdue University, 1919; "Electric Range for the Home", Harriet C. Brigham, Bulletin 102, Engineering Extension Service, Iowa State College, 1929; "Baking Vegetables Electrically", V. W. Swartz, Scientific Paper No. 167, College of Agriculture and Exp. Sta., State College of Washington; Report No. 86956 for Electromaster Inc., The Electrical Testing Laboratories, New York, 1930; Private communication from the Bureau of Standards, 1930.

available to the public, this investigation was undertaken for the purpose of determining, first, the efficiency and time of heating of the various surface units and, second, the merits of different types of ovens on representative ranges now on the market.

DESCRIPTION OF STOVES AND UTENSILS

General features.—The ranges used in the study have been designated as A, B, C, D, and E. The important dimensions of each stove are listed in Table 1. In Table 2 are listed the general features. All of the stoves were equipped with convenience outlets and reciprocating and load-balancing switches. On stove E all of the units were individually fused and a master switch controlled the entire stove circuit.

TABLE 2.—*General features*

Stove	Price class	Exterior finish	Plating	Wiring	Accessibility for repairs
A	$175	White enamel	Chromium on rim of oven door	Simple	Easy
B	$175	Gray enamel	None	Simple	Easy
C	$125	White enamel	None	Too many wires	Hard to get at lead wires
D	$125	White enamel	Small chromium band on rim of oven door	Simple	Awkward
E	$200	White enamel	Chromium on rim of oven door and around bottom of stove	Simple	Easy

Surface units.—The important features of the various types of surface units are given in Table 3 and in Figures 1 to 10. On all of the stoves, the surface units had three heat positions, HIGH, MEDIUM, and LOW. HIGH used the full

TABLE 3.—*Surface units*

Stove	No. of units	Type	Watt rating	Diam. of rim	Diam. of unit	Insulator block	Location on stove
				Inches	*Inches*		
A	3	Open	2000	10⅜	8½	Pressed asbestos	Right front
		Tubular	1200	10⅜	5¾	None	Left front
		Open	1000	10⅜	6⅝	Pressed asbestos	Rear center
		Solid [1]	2000	10⅜	8½	Pressed asbestos	Left front
		Solid [1]	1000	10⅜	6¾	Pressed asbestos	Rear center
		Tubular [1]	2100	10⅜	8	None	Right front
B	3	Solid	2250	9½	8¼	Asbestos	Right front
		Solid	1500	9½	8¼	Asbestos	Left front
		Open	1200	9½	6¼	None	Rear center
C	3	Open	2000	9¼	8	None	Front center
		Open	1250	8	7	None	Rear left
		Solid	1100	8	6½	None	Rear right
D	4	Cone & reflector	1300	8	6½	None	Right front
		Cone & reflector	1300	8	6½	None	Left front
		Cone & reflector	1300	8	6½	None	Right rear
		Cone & reflector	1300	8	6½	None	Left rear
E	4	Open	1500	9	8	Composition block	Right rear
		Solid	1500	9	7½	None	Right front
		Open	1000	9	5¾	Composition block	Left rear
		Solid	1000	9	6½	None	Left front

[1] Additional equipment.

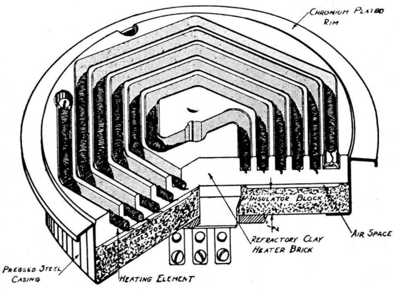

FIG. 1.—Open unit, stove A.

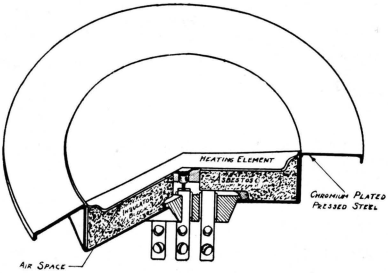

FIG. 2.—Solid cast unit, stove A.

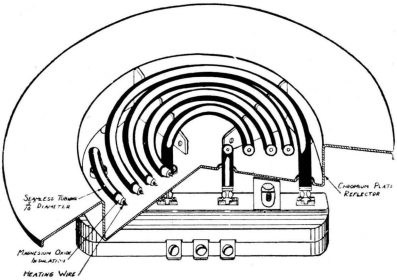

FIG. 3.—Tubular unit, stove A.

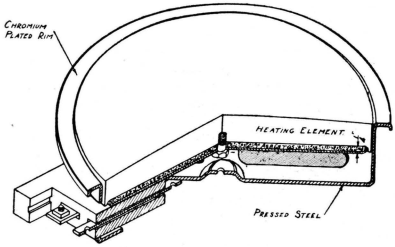

FIG. 4.—Solid unit, stove B.

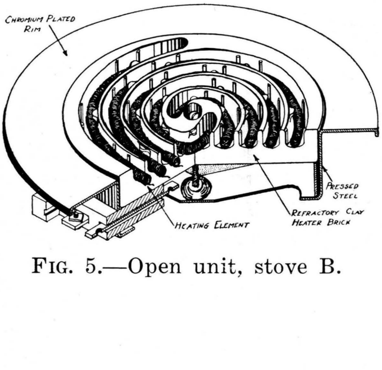

FIG. 5.—Open unit, stove B.

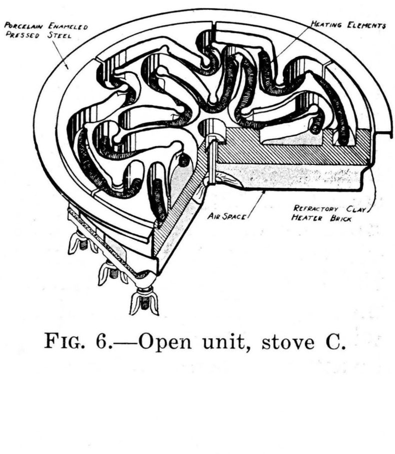

FIG. 6.—Open unit, stove C.

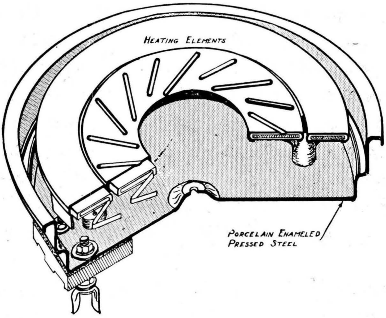

FIG. 7.—Solid unit, stove C.

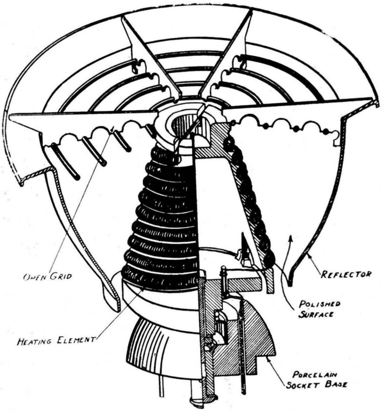

FIG. 8.—Cone and reflector unit, stove D.

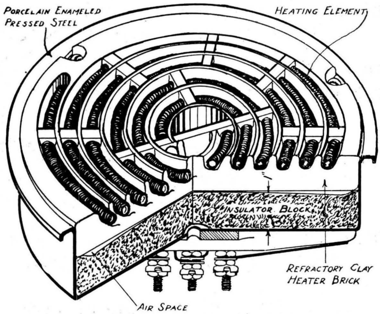

FIG. 9.—Open unit, stove E.

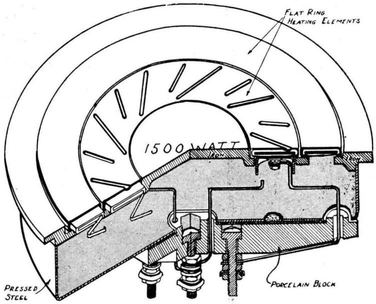

FIG. 10.—Solid unit, stove E.

power rating of the unit, MEDIUM used half the power rating of HIGH, and LOW used one-fourth of the power rating of HIGH. Hence, for equal time periods, HIGH used the full energy of the unit, MEDIUM used one-half as much energy as HIGH, and LOW one-fourth as much energy as HIGH. On stoves A and E, the two heating elements were connected in series for HIGH, with a potential of 220 volts across the combination. The two heating elements on stoves B and C were also connected in series for HIGH, but the application of voltage was different. Because of the construction of the switch, a potential of 110 volts was applied across each heating element, the total potential being 220 volts. With the application of voltage in this manner, different current readings were obtained in the outer wires of the three-wire circuit, if the resistances of the two heating elements were not equal. *Thus on stoves B and C* it was necessary to take current readings in both lines L_1 and L_2 when the unit was on HIGH (see Fig. 28). The two heating elements on stove D were connected in parallel with an applied voltage of 110 volts across the combination for HIGH. On all of the stoves a single heating element with a potential of 110 volts was used for MEDIUM, while both heating elements connected in series with a potential of 110 volts were used for LOW. The units on stoves B and E were rated at 110-220 volts, while those for stoves A, C, and D were rated at 115-230 volts.

Figure 8 shows the unit of stove D equipped with an open grid. Two of the grids, however, have at the center a thin metal baffle, 3 inches in diameter. Since the only variable feature of the units is the grid, a complete description would require the terms "cone and reflector baffle" and "cone and reflector open", but in order to abbreviate the terminology, the words "baffle" and "open" will be used in future designations. The surface characteristics of the solid-type units are shown in Figures 11 to 16 inclusive. The figures portray only enough of the unit and utensil to show the faulty contact between unit and pan. For best results the surface of the unit should make complete contact with a flat-bottomed pan.

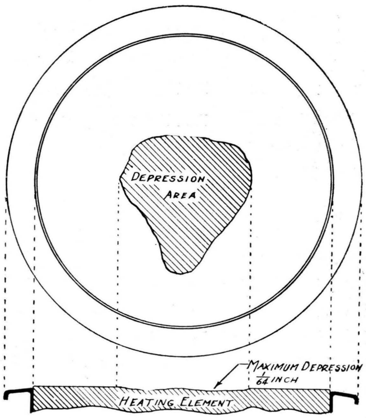

FIG. 11. — Surface condition of 2,000-watt solid unit, stove A.

FIG. 12.—Cross-section of 1,000-watt solid-unit heating element, stove A.

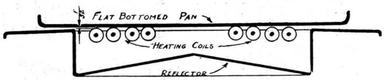

FIG. 13. — Cross-section of 1200-watt tubular unit, stove A.

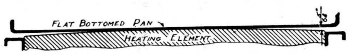

FIG. 14. — Cross-section of solid-unit heating element, stove B.

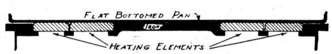

FIG. 15. — Cross-section of 1500-watt solid-unit heating element, stove E.

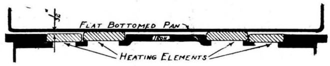

FIG. 16. — Cross-section of 1,000-watt solid-unit heating element, stove E.

Ovens.—Table 4 is a tabulation of the important features of the ovens studied. The oven-heating units are shown in Figures 17 to 21. Only one unit, rated at 2,000 watts, 230 volts, was used on stove D. It was placed about 4 inches from the bottom of the oven. The remaining stoves had a unit at both top and bottom of the oven, each rated at 1500 watts. A baffle was used over the lower unit of ovens A, B, C, and E to prevent baking by direct radiant heat.

TABLE 4.—*Ovens*

Stove	Lining	Baffle		Insulation	Ventilation
		Type	Location		
A	Blue enamel	Removable	1¼″ above unit	Mineral wool	Fixed
B	Black enamel	Removable	1½″ above unit	Mineral wool	Adjustable
C	Blue enamel	Integral with unit	Immediately above unit	Mineral wool	Adjustable
D	Chromium plate	None	....	Air	None
E	Aluminum	Integral with unit	1½″ above unit	Asbestos cell	Adjustable

Stove	Thermostat		Oven circuit indicator	Tightness of door fit
	Type	Location		
A	Spiral bimetallic strip, 110 v. magnetic relay	Right side, upper back corner	None	Fair
B	Flat bimetallic strip, 110 v. magnetic relay	In the door	Push button	Fair
C	Spiral bimetallic strip, mercoid switch	Left side, upper front corner	Red light	Poor
D	Nitrogen pressure thermometer, mercoid switch	Middle of heating element	Red light	Poor
E	Flat bimetallic strip, 220 v. magnetic relay	Upper center, right side	Red light	Good

The effectiveness of the mineral-wool insulation used in ovens A, B, and C depends upon the uniformity of packing. Upon removal of the exterior walls it was found that the packing was quite uniform except for the doors. The door of stove A was poorly packed; in fact at two large spots the insulation was not more than ½ inch thick. The doors of stoves B and C were better packed than the door of stove A, but the packing was not entirely uniform. The oven of stove D depended upon dead-air space for insulation. The oven of stove E combined dead-air space and asbestos-cell for insulating material. The asbestos was in the form of a cellular block 2 inches thick, cut to fit exactly. This type of insulation assures a uniform packing.

Utensils.—The utensils were purchased from open stock at the local department stores; they were all nationally advertised. Table 5 gives the data for these pans. The diameters listed do not include the roll at the outside of the pan; hence

TABLE 5.—*Utensils*

Utensil No.	Type	Material	Diameter of bottom	Height	Capacity
			Inches	*Inches*	*Quarts*
1	Sauce pan	Rolled aluminum	7.000	4.250	3
2	Sauce pan	Cast aluminum	7.875	4.750	4
3	Sauce pan	Green enamel	7.250	4.250	3
4	Sauce pan	White enamel	8.250	5.000	5
5	Stock kettle	Rolled aluminum	7.875	6.875	6
6	Stock kettle	Rolled aluminum	9.000	6.875	8
7	Skillet	Cast aluminum	9.250	2.000	..
8	Skillet	Cast iron, black	9.500	1.870	..

Utensil No.	Weight		Condition of bottom	Lid fits pan
	Without cover	With cover		
	Pounds	*Pounds*		
1	0.930	1.117	Recessed	Tight
2	1.672	2.273	Concave upward, slight	Tight, vapor seal
3	1.508	2.007	Concave upward, great	Poor
4	1.922	2.585	Concave upward, great	Fair
5	0.821	1.101	Concave upward, great	Tight, clamped
6	1.578	1.937	Recessed	Tight
7	2.023	....	Concave downward, great	....
8	4.759	....	Concave downward, great	....

they denote only the surface which makes contact with the unit. Cross-section views of the utensils are shown in Figures 22 to 27.

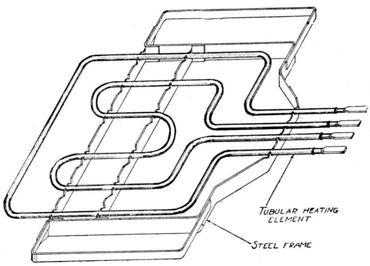

FIG. 17.—Oven unit, stove A.

APPARATUS AND GENERAL TEST METHODS

Measurement of energy.—The stoves were operated on a 110-220 volt, three-wire alternating-current circuit. A General Electric Type MIRS induction voltage regulator was used to regulate voltages of 100 to 120 volts and 200 to 240 volts. For tests requiring regulation of potentials beyond the range of the induction regulator, suitable resistance was introduced into the line in front of the regulator. Both current and potential were measured with Weston Model 155 instruments. Currents greater than 10 amperes were measured by using a Weston Model 461 current transformer in con-

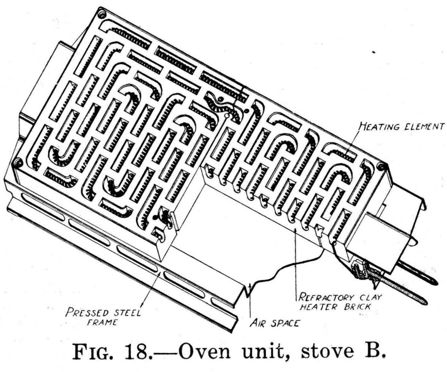

FIG. 18.—Oven unit, stove B.

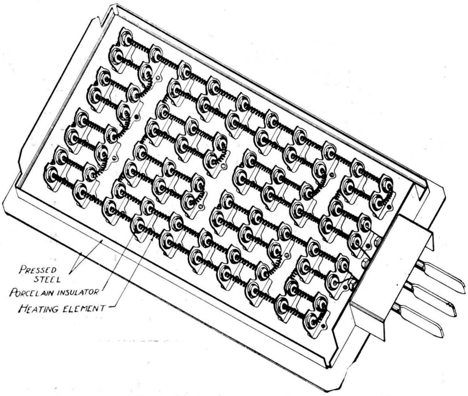

FIG. 19.—Oven unit, stove C.

junction with the 5-ampere range ammeter.

Energy was measured by a type H-C Sangamo watt-hour meter.[5] A potential-current-time product was used to check this watt-hour meter energy.[6] For tests of long duration, that is, any time over one-half hour, the time was measured by an Elgin watch, which had an error of about one minute per week. A stop watch calibrated against the Elgin watch was used for short-time tests. The potential-current product was checked against a Weston Model 310 single-phase wattmeter and found to differ by about 0.9 per cent, which is within the limits of assigned error for the watt-hour meter.

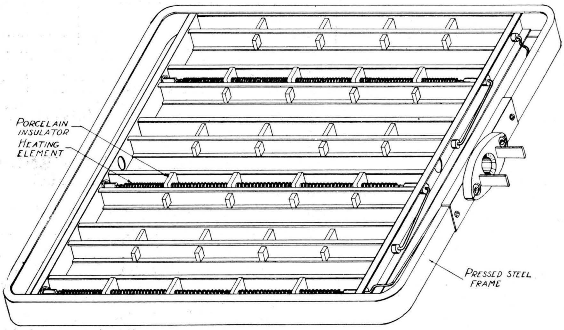

FIG. 20.—Oven unit, stove D.

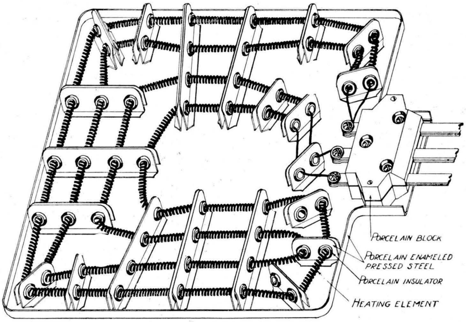

FIG. 21.—Oven unit, stove E.

[5] Originally, readings on this instrument were accurate to 10 watt-hours, but by increasing the length of each mark, the length of the pointer, and the number of marks on the 10 watt-hour dial, readings of 2.5 watt-hours could be made with greater accuracy and readings to 1 watt-hour closely estimated.

[6] Because of the absence of inductance and capacitance in the test circuit, no power factor had to be considered in the potential-current-time product. For all tests the load was a straight resistance.

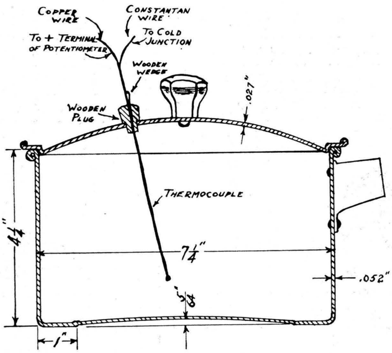

FIG. 22.—Cross-section of utensil 1, including thermocouple.

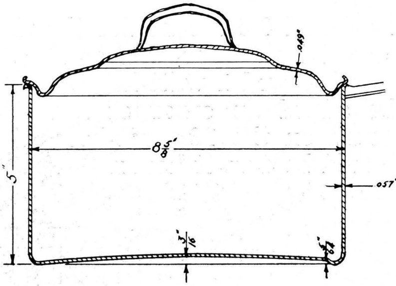

FIG. 25.—Cross-section of utensil 4.

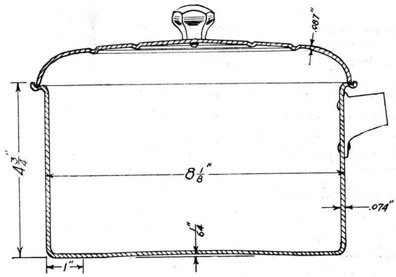

FIG. 23.—Cross-section of utensil 2.

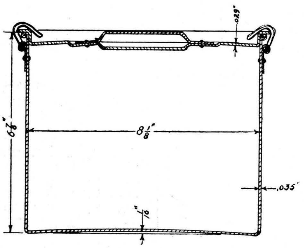

FIG. 26. — Cross-section of utensil 5.

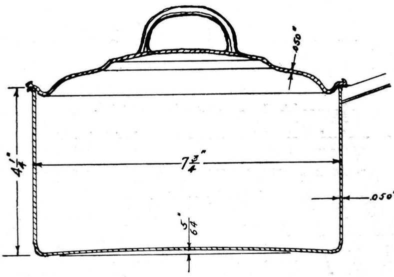

FIG. 24.—Cross-section of utensil 3.

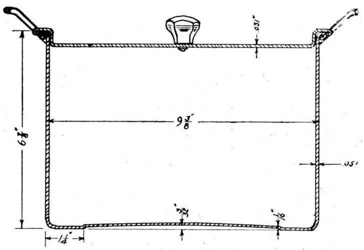

FIG. 27.—Cross-section of utensil 6.

In order to determine how closely the energy as measured by the watt-hour meter should agree with the energy calculated from the potential-current-time product, errors were arbitrarily assigned to the watt-hour meter, voltmeter, ammeter, and time readings. Maximum errors allowed were: 0.5 volt for the potential, 0.01 ampere for the 5-10 ampere range, and 0.02 ampere for the 20-ampere range for the current and 0.5 second for the time. The allowable error on the watt-hour meter was assigned as 1 watt-hour on the initial reading and 1 watt-hour on the final reading. To this should be added an error of 2 watt-hours due to slippage in the gears on the 10 watt-hour dial, so that the maximum error would be 4 watt-hours.

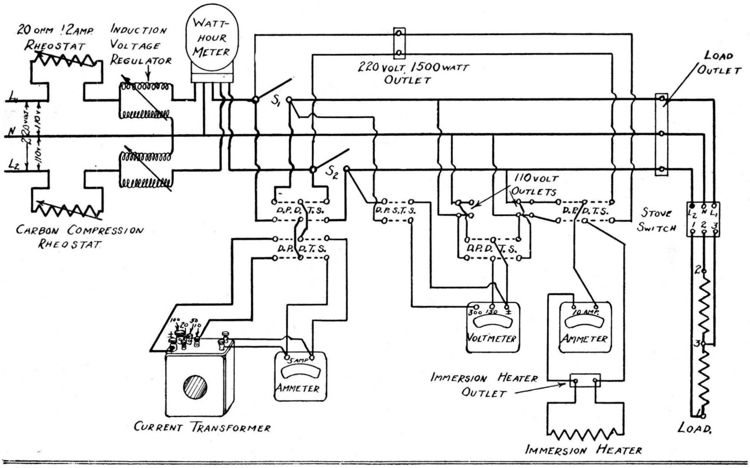

FIG. 28.—Wiring diagram of power table.

Circuit $1=L_1$ and N. Circuit $2=L_2$ and N. S_1 and S_2=heavy knife switches. D.P.D.T.S.=double-pole double-throw switch. D.P.S.T.S.=double-pole single-throw switch.

For convenience, the various instruments used for measuring and checking energy and voltage were mounted on a "power table", so wired that the instruments could be connected to any desired range and circuit by closing the proper switches. Figure 28 shows the wiring diagram of this table.

Measurement of temperature.—Temperatures from 32° to 700° F. were measured by copper-constantan thermocouples connected either to a Leeds & Northrup portable potentiometer or a Weston Model 322 pyromillivoltmeter.[7] These couples were calibrated at the boiling point of water, at the boiling point of naphthalene, and at the melting point of lead, and were found to agree exactly with the e.m.f.'s published by the Leeds & Northrup Co. For temperatures too far beyond the calibrated range of the copper-constantan couples, that is from 700° to 1800° F., iron-constantan thermocouples of No. 22 wire connected either to a high-range portable

[7] For all tests using thermocouples, the cold junction was kept at the temperature of melting ice.

potentiometer or a pyromillivoltmeter equipped with a suitable multiplier were used. The temperature of the hot element wires was measured by a Leeds & Northrup Morse-type optical pyrometer. Since all of the literature published by the stove manufacturers for the consumers' benefit and the thermostat markings are in Fahrenheit, that scale of temperatures is used throughout this bulletin.

By using a system of threads for parallax readings, the potentiometer could be read to 0.02 millivolt with an allowable error of 0.01 millivolt. The pyromillivoltmeter could be read to 0.05 millivolt with an error of 0.02 millivolt and when a magnifying lens was used this instrument could be read to 0.02 millivolt with an error of 0.01 millivolt. Translated into temperature for a copper-constantan couple, it is possible to measure to about 0.07° F. with the portable potentiometer and the magnified readings of the pyromillivoltmeter as ordinarily used. This temperature can be given only

TABLE 6.—*Resistance of units*

Stove	Unit	Resistance in ohms							
		Before use				After use			
		R′	R″	R	R′+R″	R′	R″	R	R′+R″
A	1000 open	24.84	25.04	49.80	49.84	....	....	....	....
	2000 open	11.16	12.35	23.49	23.51	11.29	12.65	23.88	23.94
	1000 solid	24.68	24.26	48.94	48.94	24.46	24.72	49.13	49.18
	2000 solid	11.54	11.86	23.38	23.40	11.54	11.88	23.36	23.42
	2100 tubular	....	....	....	....	12.04	12.51	24.50	24.55
	1200 tubular	21.90	21.07	42.94	42.97	....	21.09	....	....
	1200 tubular (new unit)	....	....	....	....	21.45	20.04	41.43	41.49
	Lower oven	15.03	16.77	31.75	31.80	15.23	16.97	32.15	32.20
	Upper oven	15.81	16.47	32.24	32.28	15.83	16.57	32.35	32.40
B	1200 open	24.16	24.38	48.51	48.54	24.14	24.38	48.45	48.52
	2250 solid	9.70	9.70	19.36	19.40	9.73	9.90	19.57	19.63
	1500 solid	14.30	14.21	28.47	28.51	14.21	14.09	28.22	28.30
	Lower oven	13.71	13.28	26.94	26.99	13.80	13.72	27.43	27.52
	Upper oven	13.71	13.81	27.47	27.52	13.67	13.78	27.38	27.45
C	1100 solid	25.21	21.39	46.57	46.60	24.94	20.90	45.77	45.84
	1250 open	17.89	19.80	37.67	37.69	18.37	20.61	38.93	38.98
	2000 open	12.56	12.21	24.76	24.77	12.93	12.94	25.82	25.87
	Lower oven	....	....	16.18	....	....	....	16.39	....
	Upper oven	....	....	16.15	....	....	....	16.39	....
D	Cone 1	16.85	16.78	33.61	33.63	17.51	17.50	34.95	35.01
	Cone 2	16.92	17.15	34.06	34.07	17.75	17.52	35.20	35.27
	Cone 3	16.80	16.74	33.53	35.54	....	....	....	....
	Cone 4	16.96	16.75	33.68	33.71	17.70	17.53	35.13	35.23
	Oven	....	....	25.88	....	....	....	26.50	....
E	1500 solid	14.68	17.88	32.53	32.56	14.62	17.65	32.22	32.27
	1000 solid	21.33	25.35	46.67	46.68	20.93	25.04	45.91	45.97
	1500 open	15.30	15.30	30.60	30.60	15.56	15.55	31.06	31.11
	1000 open	24.66	24.36	49.00	49.02	24.90	25.22	50.05	50.12
	Lower oven	15.01	15.02	30.00	30.03	15.43	15.31	30.68	30.74
	Upper oven	15.13	15.05	30.15	30.18	15.05	15.06	30.04	30.11

R′ is the resistance of one heating element, R″ is the resistance of the other heating element, and R is the combined resistance of R′ and R″ in series.

approximately, for the temperature-e.m.f. curve is not a straight line. Its slope decreases for higher temperature.

Weighing.—All weighing was done on a Fairbanks beam-balance with standardized weights ranging from 5 pounds to 1/16 of an ounce.

Resistance measurements.—Before the stoves were used the resistance of the cold heating elements was measured with a Wheatstone bridge box, equipped with a sensitive galvanometer. When the experimental work was completed, the resistance was again measured on the same Wheatstone bridge box in order to determine any change in the resistance of the units. Table 6 shows the comparison of resistances. These measurements indicate a slight degree of deterioration for open units. However, the units were not used long enough to permit any definite conclusions about serious deterioration.

PART I—SURFACE UNITS

A few of the reports available to the public have listed the efficiency of certain types of units, but none of the recent reports have compared the efficiency and time rate of heating of units used on modern electric stoves. A glance at the drawings of different types of units reveals a decided difference in construction of units of similar type. Besides this dissimilarity there are the different types to consider.

EXPERIMENTAL PROCEDURE

The various factors determining efficiency are: (1) the initial condition of the units, whether hot or cold, (2) the utensils, (3) the amount of water, (4) the temperature change of the water, (5) the evaporation loss, and (6) the duration of the test. Hence it was necessary to divide the experimental tests into three groups:

I.—The input tests for the determination of efficiency for short-time periods,

II.—The input tests for the determination of efficiency for long-time periods,

III.—The output tests for all efficiency calculation.

SCHEDULE OF TESTS

Group I.—The tests in this group were divided into three sections: (1) cold starts with the cover on the utensil, (2) hot starts with the cover on the utensil, and (3) hot starts with the cover off the utensil. Hereafter the tests in this group will be referred to as COLD START, COVER ON; HOT START, COVER ON; and HOT START, COVER OFF.

Group II.—The type of tests considered in this group has been designated as prolonged boiling. The tests were operated with both cold and hot starts with the cover on the utensil.

Group III.—This group consists of all the tests devised to determine the output by the use of an immersion heater.

METHOD OF TESTS

Group I.—For all tests in Group I, the unit was operated on HIGH. The effect of the amount of water was determined by using successively 4, 3, 2, and 1 pounds of distilled water in each utensil. In order to decrease the number of tests and to avoid duplication between pans of similar material, not all the utensils were used on each unit. After reducing the number of tests to a minimum, a total of 1,432 tests were made in this group, 27 per cent being repeat tests. Table 7 shows the pan numbers with the units on which they were used and Table 8 shows the relation between the size of the pan bottom and the size of the unit. Follow-

TABLE 7.—*Utensils used with each unit*

Stove	Unit	Utensils
A	2100 tubular	1, 2, 3, 4, 5, 6
	2000 open	1, 2, 3, 4, 6
	2000 solid	1, 2, 3, 4, 6
	1000 solid	1, 2, 3, 4, 5
	1200 tubular	1, 2, 3, 4, 5
	1000 open	1, 2, 3, 4, 5
B	2250 solid	1, 2, 3, 4, 6
	1500 solid	1, 3, 4, 5, 6
	1200 open	1, 2, 3, 4
C	2000 open	1, 2, 3, 4, 6
	1250 open	1, 3, 4, 5
	1100 solid	1, 2, 3, 4
D	1300 baffle	1, 2, 3, 4, 6
	1300 open	1, 3, 4, 5, 6
E	1000 solid	1, 2, 3, 4, 6
	1000 open	1, 2, 3, 4, 6
	1500 solid	1, 3, 4, 5, 6
	1500 open	1, 2, 3, 4

TABLE 8.—*Size of utensil vs. size of surface unit*

Stove	Unit	Pans which fit unit	Pans larger than unit	Pans smaller than unit
A	2100 tubular	4	6	1, 2, 3, 5
	2000 solid	4	6	1, 2, 3, 5
	2000 open	4	6	1, 2, 3, 5
	1000 solid	1	2, 3, 4, 5, 6	....
	1200 tubular	1	2, 3, 4, 5, 6	....
	1000 open	1	2, 3, 4, 5, 6	....
B	2250 solid	4	6	1, 2, 3, 5
	1500 solid	4	6	1, 2, 3, 5
	1200 open	....	1, 2, 3, 4, 5, 6	....
C	2000 open	2, 4, 5	6	1, 3
	1250 open	1, 3	2, 4, 5, 6	....
	1100 solid	....	1, 2, 3, 4, 5, 6	....
D	1300	2, 5	4, 6	1, 3
E	1500 solid	....	2, 4, 5, 6	1, 3
	1500 open	2, 5	4, 6	1, 3
	1000 solid	1	2, 3, 4, 5, 6	....
	1000 open	....	1, 2, 3, 4, 5, 6	....

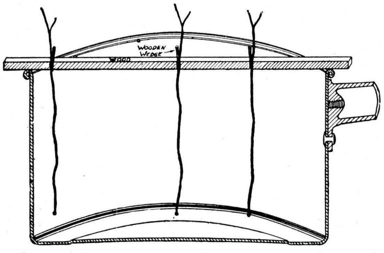

FIG. 29.—Arrangement of thermocouples for open-pan test.

ing each test the water was weighed to find the loss due to evaporation. Temperatures were read every minute. For all of the tests, the temperature of the water was raised from 72° to 206° F. This temperature change was chosen for three reasons: (1) the initial temperature was near room temperature; (2) by stopping the test at a temperature slightly below the boiling point, the evaporation loss was small; and (3) the e.m.f.'s for these temperatures are convenient when copper-constantan couples are used.[8] The COLD START, COVER ON tests were made with the unit at room temperature at the beginning of the test.[9] In the original tests only the initial and final readings of the watt-hour meter were recorded. The ammeter was read at three-minute intervals and the voltage held constant at 220 volts with the exception of stove D, which was kept at 110 volts. In the repeat tests, in order to check the energy and current more closely, watt-hour readings were taken every two minutes and current readings every minute. The voltage was regulated as in the original tests. By taking current readings every minute a better value of Ia could be obtained.[10] The HOT START, COVER ON and OFF tests were usually made following a cold-start test. For all hot starts, the unit was heated long enough to make certain that the stored heat had reached a maximum.

Group II.—The prolonged boiling tests were all made with the cover on the pan. Four pounds of distilled water were used for each test and the temperature of the water was measured with a single copper-constantan couple connected to the potentiometer as shown in Figure 22. The voltage was held constant at 220 and 110 volts. For all the prolonged boiling

[8] Preliminary tests indicated that only a single couple was necessary for tests with the cover on the utensil. For the tests with the cover off the utensil, better measurements were obtained by using three copper-constantan couples in parallel, particularly in cases where convection currents were not uniformly distributed throughout the entire volume of water. Figure 22 shows how the couple was held in place for COVER ON tests and Figure 29 shows the arrangement of the couples for COVER OFF tests. The couples were kept the same distance from the pan bottom for all tests. The only change in technique made in this group as the tests progressed was the frequency with which energy and current readings were taken.

[9] This series of tests may be divided into the original and repeat. The method of taking energy and current readings for both sorts of test for cold and hot starts was identical.

[10] This value of Ia is quite important when used in a VIat product to check the energy given by the watt-hour meter. V is the potential in volts, Ia is the average current in amperes, and t is the time in hours.

tests the complete time was one hour. After each test the water was weighed to determine the evaporation loss. The utensils used were selected following the tests of Group I as the ones best suited to the unit.[11]

Group III.—The tests in Group I and Group II constitute the input tests. Immersion-heater tests were designed to find, experimentally, the output.[12] Three immersion heaters rated at 1200, 1500, and 2100 watts, respectively, were built

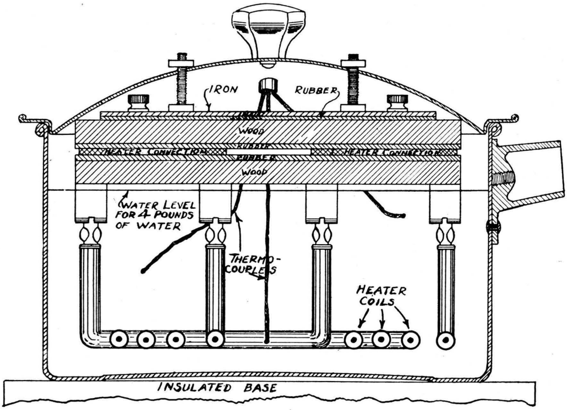

FIG. 30.—Cross-section of immersion heater in utensil 1.

from the tubular units of stove A. A cross-section of the heater, utensil, and arrangement of thermocouples and an immersion heater element are shown in Figures 30 and 31. For the COVER OFF tests the heater was fastened to a narrow strip of wood which rested on the sides of the utensil. The tem-

[11] For both cold and hot starts, the switch was turned to HIGH at the beginning of the test. Just before the water began to boil, the switch was turned to OFF. The water was raised to the boiling point and generally continued boiling for some time on stored heat. As often as was necessary to keep the water boiling the switch was turned to LOW. The amount of heat which the unit and utensil were able to store determined the frequency of this operation. Two kinds of boiling were considered, gentle boiling and violent boiling. This was necessary when considering the radiation and convection loss of the utensil at the boiling point of water. During each test both gentle and violent boiling occurred. For all the cold-start tests the current was read every minute. Only the initial and final energy readings were taken for each switch position in the original tests, while the energy was read every two minutes for the repeat tests. For the original hot-start tests the current was read every three minutes and only the initial and final energy readings were recorded for each change of switch position. For the repeat tests the ammeter was read every minute and the watt-hour meter every two minutes while the unit was on HIGH and LOW. With the increased number of readings the results were more precisely checked.

[12] For the short-time tests the minimum output is the heat necessary to raise a mass of water from 72° to 206° F., and for the actual output the amount of heat necessary to raise the temperature of the pan from 72° to 206° F. must be added to the minimum case. For long-time tests the minimum output is the heat necessary to raise 4 pounds of water from 72° to 212° F. and the actual output is the heat required to raise the temperature of the water and pan from 72° to 212° F. plus the radiation and convection loss of the pan and the evaporation loss of the water during boiling.

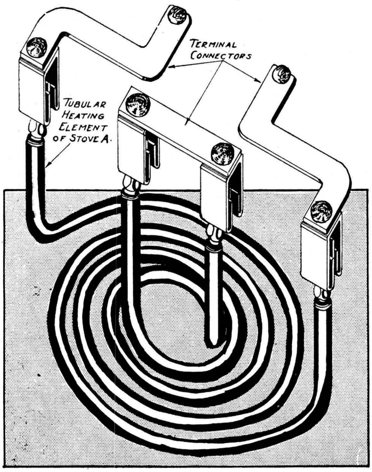

FIG. 31.—Immersion heater coil with terminal assembly.

perature was measured by three couples in parallel. The same amount of water and the same pans were used as for the input tests. The pan was placed on a base made of insulating board. For all the output tests, the energy-time curves of the input tests were duplicated as nearly as possible; thus the radiation and convection loss of the utensil should approximate that of the input test. The voltage was regulated so that the input was kept constant. The desired potential was found by a trial-and-error method. Energy readings were recorded every two minutes and ammeter readings every minute. At the end of the test the water was weighed to determine the evaporation loss.

In order to compute one of the outputs for the prolonged boiling tests the radiation and convection loss at the boiling point of water was found. The apparatus was set up as in the preceding closed-cover immersion-heater tests. Four pounds of distilled water were used in each test. The potential was adjusted until an input was found which would keep the water gently boiling; then this input was held constant for one hour. The same procedure was followed for violent boiling. This constant input would just compensate for the radiation and convection loss of the pan. Evaporation loss was recorded.

RESULTS

Temperature as a function of time of heating.—Representative curves (Fig. 32) have been chosen to compare the temperature of the water with the time of heating for the various types of surface units. For utensils other than No. 1, these curves would be slightly shifted either to the right or the left, the shift depending upon the relation of the utensil to the unit. All of the curves except 3 and 4 show regularity in change of temperature with time. Probably the decrease in slope after the first six minutes for No. 3 is due to the change in the rate of absorption of heat by the reflector. At the beginning of the test some time was necessary for the cold surface of the reflector to become sufficiently hot for heat

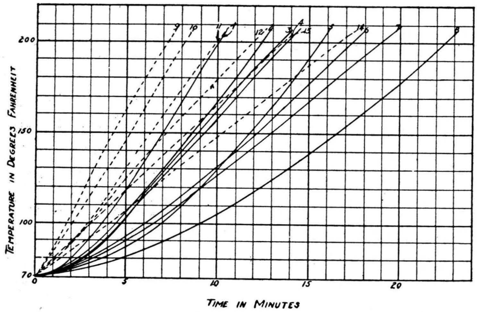

FIG. 32.—Typical heating curves for various surface units.

Solid line=cold start; broken line=hot start. Data taken from utensil 1 tests with four pounds of water: (1) large tubular, (2) large open, (3) small tubular, (4) cone and reflector, (5) large solid, (6) small flat ring, solid, (7) small open, (8) small solid, (9) large tubular, (10) large solid, (11) large open, (12) cone and reflector, (13) small solid, (14) small open.

to be rapidly transferred by conduction to the under surface and lost. As the temperature of the reflector increased more heat was lost by radiation and convection, leaving less available to be transferred to the utensil and water. The same explanation probably holds for curve No. 4 for the "cone and reflector" units of stove D. If the temperature-time curves for both open units of stove E were plotted they would exhibit the same change in slope when aluminum pans were used. Probably the change in the rate of absorption of heat by the unit, coupled with the more rapid loss of heat at higher temperature by the aluminum vessels when compared to enameled vessels, accounts for this change in slope.[13] (See Table 9.) For all the hot-start curves a change in slope was due to a change in the rate of transfer of heat as the time increased. Usually the transfer of heat to the utensil was more rapid at the beginning of the test because of the amount of heat stored in the unit. Since the same conditions of stored heat could not be obtained exactly for each hot start, considerable variation in the time necessary to heat the same quantity of water for different tests would be expected. The personal estimation of the proper condition of the unit for a hot test is a deciding factor in this type of test. Probably a linear variation in the times required to heat various quantities of water in the same pan from 72° to 206° F. was the best assurance that the hot conditions of the unit were all similar at the beginning of a test.

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[13] Supplementary tests showed that the exterior temperature of the aluminum pans followed very closely the temperature of the water, while the exterior temperature of the enameled pans lagged several degrees behind the temperature of the water. This difference in exterior pan temperatures is probably due to the more rapid conduction of heat by the aluminum pan. The great difference in conductivity is evident when the conductivities of aluminum, steel, and porcelain are compared. At 212° F. the conductivities are: aluminum 0.49, steel 0.107, and porcelain 0.0025. Since enamel-ware utensils are porcelain-covered steel, the conductivity of the pan will be between 0.107 and 0.0025. The aluminum pan is at least five times more conductive than the enameled pans.

Time of heating and efficiency.—Two efficiencies have been calculated, a minimum efficiency and an actual efficiency.[14] When determining the efficiency for any unit and pan the same input was used for both minimum and actual efficiency. The input was the total energy used to obtain the desired temperature change of the water. Since for each specific test the input is the same for both minimum and actual efficiencies, these efficiencies will depend upon how much of the input is considered as doing useful work and how much of it is lost. The output for the minimum efficiency is the same for all short-time tests having equal quantities of water. It is the amount of heat, expressed in watt-hours, necessary to heat 4, 3, 2, or 1 pounds of water from 72° to 206° F. For the long-time tests, it is the amount of heat necessary to heat 4 pounds of water from 72° to 212° F. In the actual efficiency all heat that is not delivered to the utensil and the water is considered as loss. This efficiency represents the maximum amount of heat that the unit is able to deliver to do useful work. The factors considered in calculating the output for actual efficiency are the mass of the water, the water equivalent of the utensil, the evaporation loss, and the radiation and convection loss of the pan at 212° F. The radiation and convection loss of the utensil from 72° to 212° F. was omitted from the calculation, since it could not be calculated nor found by experimentation. Because of the low temperatures involved, however, this factor would be small. To compute the energy lost by radiation and convection at 212° F. it was necessary to know the time during which the water was gently and violently boiling. These times were determined by the input tests. The radiation and convection loss expressed in watts is given in Table 9.

TABLE 9.—*Maximum radiation and convection loss of utensils for boiling water*

Utensil No.		Gentle boiling	Violent boiling
		Watts	*Watts*
1	....	90.0	90.0
2	....	119.0	135.0
3	....	133.5	153.6
4	....	193.5	215.0
5	....	104.0	119.0
6	....	133.5	153.6

[14] About fifty immersion-heater tests were made to find experimentally the output for short-time tests. These experimental outputs are important, for they include the energy necessary to heat the water and the utensil and to supply the radiation and convection loss. However, for two reasons the tests were abandoned: first, the energy necessary to heat the immersion heater was also included, and second, the time necessary to perform the required number of tests was prohibitive.

To compute the water equivalent of the enameled pans it was necessary to determine the specific heat of enamel ware. The specific heat was determined by a method of mixtures. A portion of an enameled pan which had been previously damaged was used as the test material. The average of four trials was used as the specific heat. The result obtained was 0.124.[15] For the aluminum vessels the specific heat used was 0.217. When computing the water equivalent of the utensils, the temperature change of the pans was considered to be the same as that of the water.

For the short-time tests with covered pans no evaporation loss was considered in the output. Upon condensation of the water vapor the heat which was used to vaporize the water was considered as given up to the cover and the walls of the pan. It is by this method that the cover must receive most of its heat, because the imperfect contact between the cover and the side walls will not allow sufficient transfer of heat by conduction to account for the temperature of the cover. For the COVER OFF tests, whatever vapor was lost was added to the output.[16]

For short-time tests the formula for computing the actual efficiency for covered utensils was:

$$\text{Percentage of efficiency} = \frac{[0.2928\ (m+w)\ (T_1 - T_0)]}{\text{Input in watt-hours}} \times 100\% \quad (1)$$

For the uncovered utensils the formula was:

$$\text{Percentage of efficiency} = \frac{[0.2928\ (m+w)\ (T_1 - T_0)] + 17.8c}{\text{Input in watt-hours}} \times 100\% \quad (2)$$

where m is the mass of water in pounds
w is the water equivalent of the pan in pounds
T_1 is the final temperature in degrees Fahrenheit
T_0 is the initial temperature in degrees Fahrenheit
c is the amount of water vaporized expressed in ounces
0.2928 is the conversion factor to change B.T.U.'s to watt-hours
17.8 the heat in watt-hours necessary to change 1 oz. of water at 206° F. to vapor at 212° F.

The formula for computing actual efficiency for long-time tests was:

$$\text{Percentage of efficiency} = \frac{[0.2928\ (m+w)\ (T_1 - T_0)] + (at' + bt'') + 17.7c}{\text{Input in watt-hours}} \times 100\% \quad (3)$$

where m is the mass of water in pounds
w is the water equivalent of the utensil in pounds

[15] This result is not to be considered as a precision measurement.

[16] Since most of the vaporization takes place near or at the boiling point, the evaporation loss for all tests has been computed on the basis of all the vaporization occurring at the boiling point. The error introduced by this assumption is small.

T_1 is the boiling point of water in degrees Fahrenheit
T_0 is the initial temperature of the water in degrees Fahrenheit
a is the radiation and convection loss in watts for gentle boiling
b is the radiation and convection loss in watts for violent boiling
t′ is the time in hours for gentle boiling
t″ is the time in hours for violent boiling
c is the evaporation loss expressed in ounces
0.2928 is the conversion factor to change B.T.U.'s to watt-hours
17.7 is the heat in watt-hours necessary to change 1 ounce of water at 212° F. to vapor at 212° F.

The efficiencies for all units and utensils for both hot and cold start short-time tests are given in Tables 10 to 14. The efficiencies for the long-time tests are given in Tables 15 and 16. The efficiencies are not the only important features of surface units, for a complete analysis requires a comparison of the time rate of heating and the distribution of time when the switch is on HIGH, LOW, or OFF.

Comparisons of the time and energy necessary to heat four pounds of water from 72° to 206° F. in each utensil on each unit for COLD START, COVER ON; HOT START, COVER ON; and HOT START, COVER OFF are shown in Tables 17, 18, and 19. In these tables the units are arranged so that the time and energy are listed in ascending order. Supplementing the energies are the minimum efficiencies given in Tables 10 to 14. Pans 1, 3, and 4 have been grouped together since they were used on all units. However, these tables show that the units cannot be considered alone, for there is a definite relation between the utensil and the time of heating and energy consumption for each unit.

For short-time heating on the large open units the greatest efficiency was obtained with the enameled pans, while on the small open units it was obtained with the small aluminum pan No. 1. Both the large and small open units were least efficient when used with pans 2, 5, and 6. The reasons for these results can be easily explained. First, the transfer of heat from the unit to the utensil was almost entirely by radiation; therefore the contact between the bottom of the utensil and the unit was not an important factor. It is, however, essential that the bottom of the utensil be a good absorber of radiant energy. This requirement was met by the enameled pans and the black-bottomed aluminum pan. The second factor to consider is the relation of the diameter of the pan to the diameter of the unit. Utensil 4 exactly fits and utensil 3 almost fits the large units, while utensil 1 exactly fits the small units. In other words, utensils 3 and 4 are too large for the small units and utensil 1 is too small for the large units. Pans 1 and 3 are the same height, but owing to its larger diameter pan 3 has a larger surface for radiation and convection loss.

Thus, on the small units, utensil 1 may be used to better advantage than 3. Four factors made utensils 2, 5, and 6 undesirable to use on the open units: (1) the polished bottoms of the aluminum pans reflect a part of the radiant energy back upon the unit and less is absorbed than for the enameled pans; (2) the diameters of pans 5 and 6 are too large for either the large or small units; (3) the walls of pan 2 are too thick; and (4) the pans are too high. On all the solid cast units greatest efficiency was obtained with the cast aluminum pan 2, while least efficiency was obtained with the enameled pans 3 and 4.

The 1200-watt tubular unit was most efficient when used with utensils 1 and 3 and least efficient with utensil 2. The method of transfer of energy from the tubular unit to the utensil changed when the unit was started cold. At the beginning, the transfer was almost entirely by conduction, but as the unit continued heating the coils grew red in color so that the transfer was almost entirely by radiation. Hence for the cold start the maximum efficiency from this unit at the beginning of the heating period was obtained when the heating element made good contact with the bottom of the utensil. As is shown by Figure 13, such contact was not possible with utensil 2 but was possible with the recessed bottoms of utensils 1 and 3. Obviously, pans 1 and 3 were better adapted to the 1200-watt tubular unit than pan 2. The 2100-watt tubular unit was most efficient when used with pan 4 and least efficient with pan 6. Pan 6 was much too large for the unit. Greatest efficiency was obtained on the ring-type units when used with pans 1 and 5, but this type was least efficient with pans 4 and 6. The transfer of heat was almost wholly by conduction, but because of the small thermal mass and the thinness of the metal casing, the unit proved to be very efficient. Since the inner ring was usually elevated somewhat above the outer ring, a utensil with a recessed bottom was better adapted to the unit than a pan with a perfectly flat bottom. Utensils 4 and 6 were much too large for the ring units.

Tables 15 and 16 show that for long-time heating, greatest efficiency was obtained on all of the units when used with pans 1 and 2 and least with pans 3 and 4. The reason for this is the difference in the radiation and convection loss for aluminum and enameled pans. Since enameled pans are good absorbers of radiant energy they are also good radiators. During a sustained cooking process the radiation and convection loss of the enameled pans was far greater than that of the aluminum pans of similar size. This is shown in Table 9.

TABLE 10.—*Percentage of efficiency of surface units, stove A*

Unit	Pounds of water	Utensil 1		Utensil 2		Utensil 3		Utensil 4		Utensil 5		Utensil 6	
		Minimum	Actual	Minimum	Actual	Minimum	Actual	Minimum	Actual	Minimum	Actual	Minimum	Actual
COLD START, COVER ON													
2,000 open	4	37.6	39.0	37.3	40.3	39.6	41.5	40.5	43.0	......	......	34.2	36.8
	3	34.6	36.2	32.7	36.3	36.6	38.8	36.5	39.4	......	......	30.4	33.5
	2	29.6	31.7	27.4	31.9	30.3	33.0	32.1	35.9	......	......	24.7	28.5
	1	22.4	25.6	20.0	26.6	23.4	27.6	23.8	29.4	......	......	17.8	23.4
2,000 solid	4	29.4	30.4	34.8	37.6	26.7	27.9	25.4	26.8	......	......	27.9	30.0
	3	26.8	28.2	29.9	33.2	24.8	26.3	22.9	24.7	......	......	22.2	24.5
	2	21.1	22.6	24.4	28.4	21.4	23.3	18.5	20.6	......	......	18.4	21.2
	1	12.0	13.7	15.6	20.8	13.7	16.2	12.0	14.8	......	......	12.6	16.5
1,000 solid	4	43.5	45.0	45.0	48.5	38.0	39.7	34.5	36.6	36.6	38.2	......	......
	3	37.8	39.7	38.8	43.1	36.0	38.1	30.7	33.2	31.0	32.8	......	......
	2	33.0	35.2	30.4	35.3	29.5	32.2	25.5	28.5	26.0	28.3	......	......
	1	21.7	24.7	23.2	30.8	19.8	23.5	16.5	20.3	17.6	20.6	......	......
1200 tubular	4	60.5	62.6	47.5	51.3	60.0	62.6	57.5	61.0	56.0	58.5	......	......
	3	56.0	58.6	44.4	49.2	56.6	60.1	54.0	58.1	51.5	54.5	......	......
	2	48.8	52.1	38.8	45.0	48.0	52.5	46.8	52.2	44.4	48.1	......	......
	1	38.2	43.5	28.2	37.5	37.3	44.0	35.0	43.1	32.4	38.0	......	......
1,000 open	4	54.3	56.2	48.5	52.4	49.0	51.4	47.9	50.8	45.3	47.2	......	......
	3	47.0	49.3	43.7	48.5	47.5	50.3	43.5	46.9	39.5	41.9	......	......
	2	40.7	43.6	36.0	41.9	38.9	42.5	37.6	42.0	33.5	36.3	......	......
	1	30.5	34.8	26.1	34.8	29.7	35.1	27.4	33.8	24.4	28.6	......	......
2100 tubular	4	47.7	49.5	46.9	50.6	47.0	49.2	49.5	52.4	40.2	42.0	41.5	44.8
	3	43.5	45.5	41.9	46.5	42.8	45.4	46.1	49.8	37.6	39.8	38.2	42.1
	2	37.8	40.5	35.1	40.8	36.4	39.7	38.2	42.6	32.0	34.7	32.0	36.8
	1	27.0	30.9	25.0	33.3	26.3	31.1	26.9	33.2	23.2	27.2	21.9	28.7
HOT START, COVER ON													
2,000 open	4	46.7	48.4	55.5	60.0	52.4	54.7	71.0	75.3	......	......	49.7	53.5
	3	54.4	57.0	57.3	63.5	60.1	63.7	72.7	78.5	......	......	50.6	55.8
	2	40.5	43.5	50.0	58.1	58.5	63.9	63.7	71.2	......	......	42.9	49.5
	1	34.4	39.2	34.1	45.3	46.2	54.6	53.4	66.0	......	......	28.0	36.6
2,000 solid	4	54.5	56.4	87.8	95.0	57.5	60.0	63.2	67.0	......	......	55.0	59.3
	3	61.6	64.8	71.0	78.7	54.0	57.1	59.9	66.9	......	......	58.6	64.6
	2	63.2	67.6	79.0	91.9	65.8	71.9	46.5	57.4	......	......	59.8	69.0
	1	63.7	72.8	71.9	95.5	65.9	77.9	63.2	67.0	......	......	63.1	82.6
1,000 solid	4	70.0	72.4	87.8	94.7	55.3	58.0	49.7	52.6	76.0	79.2	......	......
	3	66.8	70.0	73.9	82.0	72.7	77.0	50.5	54.5	65.1	69.0	......	......
	2	78.2	83.8	68.1	79.1	65.5	71.5	69.3	77.4	70.0	76.0	......	......
	1	76.0	86.8	63.8	84.6	47.9	56.6	60.0	74.0	63.7	74.6	......	......

TABLE 10.—*Percentage of efficiency of surface units, stove A—Continued*

Unit	Pounds of water	Utensil 1 Minimum	Utensil 1 Actual	Utensil 2 Minimum	Utensil 2 Actual	Utensil 3 Minimum	Utensil 3 Actual	Utensil 4 Minimum	Utensil 4 Actual	Utensil 5 Minimum	Utensil 5 Actual	Utensil 6 Minimum	Utensil 6 Actual
					HOT START, COVER ON—(*Continued*)								
1200 tubular	4	73.5	76.0	57.5	62.1	71.8	75.1	64.2	68.0	59.7	62.2	......	......
	3	71.0	74.5	55.6	61.7	64.8	68.6	69.4	74.7	53.2	56.4	......	......
	2	65.9	70.5	52.7	61.2	68.6	75.0	63.7	71.1	51.0	56.6	......	......
	1	64.3	73.4	40.3	53.5	65.9	77.9	57.3	70.8	47.0	55.1	......	......
1,000 open	4	61.3	63.5	60.8	65.7	59.6	62.4	70.9	75.0	59.1	61.7	......	......
	3	67.0	70.3	65.5	72.6	66.8	70.8	70.1	75.6	61.5	65.0	......	......
	2	66.4	71.1	59.4	69.0	64.5	70.4	65.2	73.0	59.0	64.0	......	......
	1	67.0	76.5	49.5	65.6	60.4	71.4	56.5	69.7	48.8	57.1	......	......
2100 tubular	4	64.5	66.8	59.6	64.5	59.6	62.4	67.2	71.2	54.3	56.6	35.5	59.7
	3	62.5	65.5	58.0	64.5	58.7	62.1	65.9	71.0	48.8	51.6	53.4	58.9
	2	61.6	66.1	47.9	55.6	54.9	59.8	62.2	69.5	47.1	51.2	51.0	58.8
	1	55.0	62.6	44.9	59.7	50.6	60.0	58.5	72.4	42.5	49.7	42.6	55.9
					HOT START, COVER OFF								
2,000 open	4	56.9	64.1	56.4	69.0	50.5	57.9	54.0	68.5	......	......	45.0	57.9
	3	48.6	56.0	54.0	69.5	49.5	57.2	58.5	71.6	......	......	43.9	62.4
	2	52.0	59.5	37.2	52.1	52.6	65.1	59.0	77.3	......	......	35.9	57.5
	1	50.6	71.0	39.5	66.7	43.9	64.7	54.9	89.9	......	......	26.9	54.7
2,000 solid	4	69.5	77.5	80.1	91.6	47.5	55.7	47.6	60.5	......	......	54.5	69.3
	3	60.2	69.3	78.0	92.9	38.6	47.7	58.7	71.6	......	......	52.0	70.2
	2	47.9	58.9	73.8	93.0	54.5	70.5	43.4	57.0	......	......	51.0	71.6
	1	43.9	56.6	69.3	109.0	56.5	76.8	40.7	62.0	......	......	38.7	63.5
1,000 solid	4	79.5	96.5	66.6	86.2	52.4	67.3	49.5	70.5	53.2	66.1	......	......
	3	71.0	95.2	60.0	82.7	46.9	64.0	54.6	77.4	42.6	64.5	......	......
	2	71.8	92.3	62.6	91.5	58.5	79.0	40.1	69.6	42.6	67.0	......	......
	1	65.9	92.3	53.4	93.0	38.4	65.1	42.0	75.9	38.0	64.1	......	......
1200 tubular	4	66.0	78.9	45.8	61.4	60.4	80.2	56.5	76.3	49.4	64.7	......	......
	3	65.1	81.3	47.0	65.5	62.0	78.9	57.5	76.0	48.4	66.0	......	......
	2	57.2	71.9	42.5	62.0	58.0	85.0	53.4	76.0	40.3	61.0	......	......
	1	43.9	66.5	30.4	61.5	43.9	74.5	43.0	77.6	27.6	74.7	......	......
1,000 open	4	55.0	73.6	51.3	74.5	61.5	77.5	56.9	83.3	46.0	63.1	......	......
	3	56.7	74.0	48.8	74.7	57.1	74.9	47.5	75.0	43.0	63.2	......	......
	2	56.8	73.1	39.5	62.0	54.5	73.5	42.3	72.0	44.9	68.0	......	......
	1	54.1	78.9	34.6	66.3	51.0	80.9	39.5	69.1	34.0	67.1	......	......
2100 tubular	4	59.1	65.9	53.2	63.8	54.5	62.5	63.2	74.8	47.7	56.0	47.9	61.6
	3	56.2	64.9	49.4	61.7	53.6	62.2	60.2	72.8	43.5	52.6	47.5	62.1
	2	54.9	64.4	46.5	62.5	51.0	63.0	58.5	73.5	43.4	56.0	43.4	61.0
	1	52.6	71.0	37.6	59.2	44.9	61.1	52.6	74.5	37.6	55.1	38.4	65.2

TABLE 11.—*Percentage of efficiency of surface units, stove B*

Unit	Pounds of water	Utensil 1		Utensil 2		Utensil 3		Utensil 4		Utensil 5		Utensil 6	
		Minimum	Actual	Minimum	Actual	Minimum	Actual	Minimum	Actual	Minimum	Actual	Minimum	Actual
COLD START, COVER ON													
2,250 solid	4	32.8	34.0	41.9	45.2	31.8	33.2	27.4	29.0	......	......	32.2	34.8
	3	27.9	29.2	36.0	40.0	27.2	28.8	23.6	25.5	......	......	27.4	30.2
	2	24.4	26.1	28.8	33.5	20.0	21.9	22.6	25.2	......	......	21.4	24.7
	1	16.3	18.6	18.8	25.0	14.7	17.4	12.4	15.4	......	......	13.2	17.3
1500 solid	4	42.6	44.1	......	......	36.2	37.8	32.8	34.7	36.2	37.6	39.4	42.4
	3	38.6	40.5	......	......	29.4	31.1	28.4	30.7	32.7	34.6	35.6	39.2
	2	30.2	32.3	......	......	26.3	28.7	22.7	25.4	28.4	30.8	29.0	33.4
	1	18.7	21.4	......	......	17.2	20.3	14.2	17.5	18.5	21.6	15.8	20.6
1200 open	4	57.5	59.5	42.1	45.5	52.3	54.7	49.6	52.7	......	......	......	......
	3	49.2	51.5	38.8	43.1	46.3	49.1	47.0	50.6	......	......	......	......
	2	44.0	47.0	34.5	40.0	42.2	46.0	39.9	44.5	......	......	......	......
	1	32.9	37.6	24.1	32.0	31.1	36.8	31.6	39.0	......	......	......	......
HOT START, COVER ON													
2,250 solid	4	112.0	116.0	141.0	152.5	65.8	68.9	57.9	61.4	......	......	69.0	74.3
	3	106.8	112.0	208.0	230.5	66.8	70.8	76.5	82.5	......	......	77.2	85.0
	2	84.0	90.0	197.5	229.5	65.8	71.8	74.5	83.2	......	......	113.0	130.0
	1	99.0	112.8	188.0	250.0	70.5	83.5	58.1	71.8	......	......	110.0	143.4
1500 solid	4	64.5	66.8	......	......	52.4	54.8	68.6	72.8	106.8	111.0	79.0	85.0
	3	85.3	89.5	......	......	68.7	72.9	58.5	63.1	102.0	108.0	78.0	86.0
	2	88.8	95.1	......	......	70.3	76.5	65.8	73.5	116.0	126.0	98.7	114.0
	1	94.0	107.7	......	......	74.5	88.0	54.9	67.8	86.8	101.8	84.0	110.0
1200 open	4	62.7	65.0	56.0	60.6	70.2	73.5	67.9	71.9	......	......	......	......
	3	71.0	74.5	56.7	62.9	67.6	71.7	63.7	68.8	......	......	......	......
	2	68.0	73.0	55.2	64.2	63.7	69.5	59.4	66.5	......	......	......	......
	1	62.7	71.6	39.9	53.0	58.5	69.2	52.7	65.0	......	......	......	......
HOT START, COVER OFF													
2,250 solid	4	104.0	114.2	129.0	151.0	56.0	64.1	65.1	77.2	......	......	85.0	99.7
	3	98.0	109.4	129.0	158.5	57.1	66.3	67.4	83.8	......	......	94.0	109.0
	2	119.5	137.1	118.0	151.8	63.6	75.1	67.0	87.7	......	......	98.8	127.9
	1	116.0	143.0	155.0	244.0	51.3	69.9	56.5	86.0	......	......	80.7	127.8
1500 solid	4	82.3	93.0	......	......	65.0	76.4	61.5	74.5	99.4	113.6	70.9	87.2
	3	83.0	95.7	......	......	62.8	76.1	63.4	76.7	93.4	108.0	84.1	105.0
	2	84.0	98.6	......	......	60.3	78.0	57.2	75.1	85.9	105.8	100.0	132.0
	1	82.3	110.9	......	......	54.5	80.3	58.1	88.5	83.2	117.3	94.0	143.8
1200 open	4	62.5	76.6	46.9	64.2	55.3	71.0	50.6	70.0	......	......	......	......
	3	65.9	78.5	47.0	65.0	59.5	73.5	57.5	78.3	......	......	......	......
	2	56.4	72.6	39.5	59.7	54.5	73.5	52.3	77.5	......	......	......	......
	1	52.0	75.9	32.4	54.6	54.5	80.3	52.5	79.2	......	......	......	......

TABLE 12.—*Percentage of efficiency of surface units, stove C*

Unit	Pounds of water	Utensil 1 Minimum	Utensil 1 Actual	Utensil 2 Minimum	Utensil 2 Actual	Utensil 3 Minimum	Utensil 3 Actual	Utensil 4 Minimum	Utensil 4 Actual	Utensil 5 Minimum	Utensil 5 Actual	Utensil 6 Minimum	Utensil 6 Actual
						COLD START, COVER ON							
2,000 open	4	45.1	46.7	39.2	42.3	44.1	46.1	42.9	45.3	......	......	34.3	37.0
	3	37.8	39.6	34.8	38.6	39.6	42.0	40.0	43.0	......	......	30.4	33.5
	2	33.0	35.2	29.8	34.6	34.0	37.2	33.2	37.1	......	......	24.5	28.3
	1	24.0	27.4	20.6	27.5	25.3	29.9	22.9	28.3	......	......	16.5	21.6
1250 open	4	49.0	50.6	......	......	50.1	52.5	46.9	49.7	39.6	41.3	......	......
	3	46.5	48.7	......	......	44.6	47.3	43.0	46.3	36.4	38.6	......	......
	2	40.3	43.1	......	......	39.5	43.0	37.2	41.6	30.6	33.2	......	......
	1	30.8	35.2	......	......	27.4	32.4	26.4	32.6	22.2	26.1	......	......
1100 solid	4	58.0	60.0	60.0	64.6	61.3	64.0	52.1	55.1	......	......	......	......
	3	53.9	56.5	57.8	64.1	53.6	56.9	48.0	51.8	......	......	......	......
	2	47.4	50.6	45.0	52.5	47.5	52.0	41.4	46.2	......	......	......	......
	1	34.6	39.6	32.1	42.6	33.5	39.6	31.1	38.4	......	......	......	......
						HOT START, COVER ON							
2,000 open	4	50.4	52.0	55.5	60.0	59.1	61.9	58.5	62.0	......	......	43.6	47.0
	3	55.0	57.5	53.7	59.0	53.6	56.9	61.1	65.9	......	......	46.5	51.2
	2	53.7	57.5	52.0	60.5	53.0	57.9	54.5	61.0	......	......	40.5	46.7
	1	38.7	44.2	44.9	59.6	47.9	56.6	47.0	58.1	......	......	32.1	42.0
1250 open	4	66.5	68.7	......	......	60.1	63.9	62.5	66.1	52.6	55.0	......	......
	3	59.3	62.2	......	......	65.8	69.9	59.3	64.0	44.0	46.5	......	......
	2	60.8	65.2	......	......	55.6	60.6	60.8	67.9	48.1	52.3	......	......
	1	52.0	59.4	......	......	54.0	64.9	52.0	64.3	40.7	47.7	......	......
1100 solid	4	72.5	75.0	70.0	75.5	64.8	67.7	67.2	71.2	......	......	......	......
	3	70.6	74.0	70.0	77.8	65.0	68.9	64.8	69.9	......	......	......	......
	2	71.8	77.0	67.5	78.5	63.7	69.5	55.6	62.0	......	......	......	......
	1	69.3	79.1	59.0	78.4	49.5	58.4	50.6	62.5	......	......	......	......
						HOT START, COVER OFF							
2,000 open	4	45.7	52.8	53.1	63.8	58.3	68.5	56.5	68.5	......	......	43.5	58.0
	3	52.0	62.0	49.2	60.5	50.5	62.3	56.0	69.6	......	......	42.9	59.3
	2	49.4	60.6	44.6	61.3	47.1	61.1	53.0	69.6	......	......	38.2	57.9
	1	37.2	50.1	38.3	60.5	46.0	67.6	45.4	74.4	......	......	26.7	55.9
1250 open	4	63.7	76.5	......	......	60.1	72.5	52.0	66.0	42.6	53.0	......	......
	3	61.0	72.6	......	......	58.7	72.5	56.0	73.9	36.8	48.0	......	......
	2	51.3	63.0	......	......	57.5	74.4	50.0	71.1	41.6	58.3	......	......
	1	48.1	64.9	......	......	50.5	70.4	46.0	75.3	32.1	54.3	......	......
1100 solid	4	61.0	74.9	58.3	78.1	55.5	69.9	49.2	66.5	......	......	......	......
	3	58.5	68.5	55.9	71.0	54.0	70.5	48.0	65.3	......	......	......	......
	2	62.6	77.0	58.5	82.0	52.3	73.6	50.3	71.6	......	......	......	......
	1	59.9	83.9	39.9	67.4	47.0	74.6	43.0	70.4	......	......	......	......

TABLE 13.—*Percentage of efficiency of surface units, stove D*

Unit	Pounds of water	Utensil 1		Utensil 2		Utensil 3		Utensil 4		Utensil 5		Utensil 6	
		Minimum	Actual	Minimum	Actual	Minimum	Actual	Minimum	Actual	Minimum	Actual	Minimum	Actual
COLD START, COVER ON													
1300 baffle	4	46.9	48.5	36.4	39.4	46.0	48.2	50.1	53.1	......	......	32.1	34.6
	3	44.5	46.5	32.9	36.5	44.2	47.0	43.0	46.5	......	......	30.2	33.3
	2	37.8	40.5	29.6	34.4	37.6	41.0	38.5	43.0	......	......	26.4	30.5
	1	30.4	34.7	21.1	28.0	28.4	33.6	29.4	36.4	......	......	21.2	27.8
1300 open	4	50.0	51.7	......	......	50.1	52.5	50.5	53.5	31.4	32.7	33.8	36.4
	3	48.0	50.3	......	......	45.0	47.6	45.8	49.4	32.0	33.9	30.0	33.0
	2	41.8	44.7	......	......	40.8	44.5	40.7	45.5	28.8	31.3	24.4	28.2
	1	32.8	37.4	......	......	31.8	37.6	30.0	37.0	24.0	28.0	19.9	26.1
HOT START, COVER ON													
1300 baffle	4	50.1	52.0	41.6	45.0	51.1	53.5	57.5	61.0	......	......	36.4	39.3
	3	52.7	55.3	41.1	45.6	52.0	55.0	57.3	61.7	......	......	36.2	39.9
	2	49.4	53.0	38.9	45.2	48.6	53.0	52.6	58.8	......	......	33.3	38.4
	1	44.0	50.1	24.7	32.8	35.3	41.7	39.9	49.3	......	......	30.0	39.1
1300 open	4	56.5	58.5	......	......	56.0	58.5	59.5	63.0	38.8	40.5	39.2	42.3
	3	56.0	58.8	......	......	57.1	60.5	56.5	61.0	37.2	39.3	39.9	44.0
	2	52.6	56.5	......	......	52.6	57.5	52.1	58.2	34.2	37.2	36.4	42.0
	1	48.0	54.6	......	......	37.6	44.5	43.1	53.4	27.8	32.6	33.6	44.0
HOT START, COVER OFF													
1300 baffle	4	47.1	57.9	28.3	42.4	45.8	56.4	51.0	67.5	......	......	w.n.b.	w.n.b.
	3	45.5	48.1	30.2	44.5	45.0	58.8	47.8	63.1	......	......	w.n.b.	w.n.b.
	2	40.5	54.4	25.8	33.2	43.9	59.2	47.9	57.5	......	......	w.n.b.	w.n.b.
	1	32.9	40.6	w.n.b.	w.n.b.	40.5	59.7	34.6	68.4	......	......	w.n.b.	w.n.b.
1300 open	4	51.8	62.9	......	......	49.4	60.8	50.4	65.3	31.5	43.1	w.n.b.	w.n.b.
	3	49.4	60.6	......	......	45.6	59.7	50.7	63.1	25.0	36.3	26.4	43.5
	2	48.5	60.9	......	......	43.4	61.0	46.5	63.6	26.1	39.5	w.n.b.	w.n.b.
	1	43.0	57.8	......	......	35.1	57.7	39.5	69.1	22.3	42.8	w.n.b.	w.n.b.

NOTE: w.n.b. = would not boil.

TABLE 14.—*Percentage of efficiency of surface units, stove E*

Unit	Pounds of water	Utensil 1		Utensil 2		Utensil 3		Utensil 4		Utensil 5		Utensil 6	
		Minimum	Actual	Minimum	Actual	Minimum	Actual	Minimum	Actual	Minimum	Actual	Minimum	Actual
						COLD START, COVER ON							
1500 solid	4	47.5	49.1	47.5	51.4	45.0	47.1	42.8	45.4	......	......	42.1	45.3
	3	43.8	46.0	45.3	50.1	39.8	42.1	38.0	41.0	......	......	37.4	41.1
	2	37.6	40.3	36.9	43.0	36.8	40.0	32.5	36.3	......	......	31.0	35.7
	1	27.4	31.4	23.9	31.8	26.9	31.8	22.4	27.6	......	......	23.2	30.4
1500 open	4	45.1	46.7	44.3	47.9	45.7	47.8	43.3	45.9	......	......	36.8	39.6
	3	40.9	42.9	35.7	39.6	41.3	43.7	39.5	42.7	......	......	34.2	37.6
	2	33.3	35.7	28.7	33.4	33.4	36.5	33.4	37.3	......	......	27.5	31.7
	1	25.0	28.6	20.6	28.7	25.6	30.2	24.2	29.9	......	......	19.9	26.0
1,000 solid	4	54.0	56.0	......	......	48.3	50.5	49.1	52.0	50.1	52.3	45.4	48.9
	3	46.9	49.1	......	......	45.2	48.0	43.0	46.4	44.4	47.0	40.5	44.5
	2	40.7	43.6	......	......	36.4	39.8	35.4	39.6	38.5	41.8	33.2	38.2
	1	30.7	35.0	......	......	28.2	33.4	25.6	31.6	26.8	31.4	23.6	30.9
1,000 open	4	55.0	57.0	50.2	54.1	51.0	53.4	51.0	54.0	......	......	......	......
	3	50.0	52.5	44.2	49.0	47.5	50.3	45.0	48.7	......	......	......	......
	2	43.0	46.0	36.2	42.1	41.0	44.8	39.0	43.5	......	......	......	......
	1	33.8	38.6	26.0	34.5	32.2	38.2	28.8	35.6	......	......	......	......
						HOT START, COVER ON							
1500 solid	4	71.8	74.4	78.6	85.0	74.4	77.7	69.6	73.8	......	......	70.8	76.4
	3	76.0	79.6	72.2	80.2	71.9	76.1	73.8	80.0	......	......	68.0	74.8
	2	68.7	73.6	68.6	79.8	64.5	70.4	68.4	76.4	......	......	67.0	72.2
	1	45.2	51.5	60.0	79.8	52.6	62.3	62.7	77.5	......	......	46.5	60.7
1500 open	4	63.5	65.9	61.0	66.0	59.1	62.0	63.7	67.5	......	......	55.7	60.0
	3	63.8	66.9	60.5	67.1	65.0	68.9	65.9	71.0	......	......	56.7	62.5
	2	60.5	64.9	46.7	54.4	57.5	62.6	60.8	67.9	......	......	49.7	57.3
	1	60.4	69.0	45.5	60.3	60.8	71.9	58.5	72.3	......	......	49.4	64.6
1,000 solid	4	68.1	70.5	......	......	70.0	73.0	75.0	79.4	76.4	79.5	70.2	75.6
	3	76.5	80.2	......	......	64.8	68.6	72.7	78.4	75.5	80.0	68.1	75.0
	2	75.2	80.6	......	......	70.3	76.5	72.5	81.0	61.7	67.0	65.8	76.0
	1	58.1	66.4	......	......	62.2	73.5	58.0	71.7	62.6	73.5	52.6	69.0
1,000 open	4	68.0	70.4	62.5	67.6	73.0	76.4	62.0	65.8	......	......	......	......
	3	70.0	73.4	59.5	66.1	74.0	78.5	65.0	70.0	......	......	......	......
	2	68.5	73.2	56.8	66.0	66.6	72.7	57.5	64.1	......	......	......	......
	1	65.4	74.5	43.1	57.4	65.9	77.9	54.5	67.4	......	......	......	......

TABLE 14.—*Percentage of efficiency of surface units, stove E*—(*Continued*)

Unit	Pounds of water	Utensil 1		Utensil 2		Utensil 3		Utensil 4		Utensil 5		Utensil 6	
		Minimum	Actual	Minimum	Actual	Minimum	Actual	Minimum	Actual	Minimum	Actual	Minimum	Actual
						HOT START, COVER OFF							
1500 solid	4	69.4	80.1	69.0	82.7	63.0	74.0	62.0	74.4	......	......	58.5	73.5
	3	59.3	71.2	64.8	79.5	63.8	78.7	63.3	79.2	......	......	62.0	86.9
	2	67.3	78.0	55.3	74.3	61.0	75.4	62.2	83.0	......	......	53.0	77.5
	1	57.7	76.0	37.2	63.0	58.5	79.7	59.9	87.9	......	......	42.7	82.2
1500 open	4	58.0	67.2	53.7	64.5	60.1	69.5	67.2	79.7	......	......	48.4	62.1
	3	60.8	71.1	54.6	69.2	60.0	71.8	60.5	75.3	......	......	50.2	68.5
	2	57.6	69.3	50.0	67.2	56.5	69.8	56.0	73.6	......	......	41.4	60.5
	1	54.4	73.2	39.5	62.2	58.0	79.0	53.4	78.3	......	......	27.6	51.5
1,000 solid	4	67.5	81.0	......	......	63.9	77.8	65.0	84.4	67.2	82.6	51.0	73.0
	3	66.0	78.5	......	......	62.5	77.2	62.4	82.4	60.5	76.8	50.9	89.5
	2	56.0	72.0	......	......	61.5	81.1	57.2	78.4	59.9	79.0	47.4	78.8
	1	50.7	73.9	......	......	53.4	78.6	40.7	71.2	43.5	71.0	w.n.b.	w.n.b.
1,000 open	4	59.6	71.5	42.5	64.9	60.1	74.0	47.1	67.8	......	......	......	......
	3	62.8	79.5	42.2	63.0	54.6	71.5	44.0	66.4	......	......	......	......
	2	59.0	75.6	34.0	49.7	55.6	75.0	49.4	76.0	......	......	......	......
	1	57.0	80.2	w.n.b.	w.n.b.	46.5	68.5	35.3	61.7	......	......	......	......

NOTE: w.n.b. = would not boil.

In all of the tests the efficiency was greater when a cover was used on the utensil. In several cases when no cover was used the water could not be raised to the boiling point. This is shown in Table 13 for pans 2 and 6 on stove D, and also in Table 14 for pan 6 on stove E. Supplementary tests showed that owing to the oversized bottom of the pan when compared to the unit, there were not sufficient convection currents established to distribute the heat throughout the entire mass of water. The water boiled at the center of the pan but at the outer portions the temperature was never higher than 194° F. This was also true for pan 6 when 3, 2, and 1 pounds of water were used. All of the units except those of stove D were more efficient for hot starts than for cold starts. The exceptions were with utensils 2 and 6 for HOT STARTS, COVER OFF on stove D.

TABLE 15.—*Efficiencies for long-time tests—cold start*

Unit, stove, and utensil [1]	Evaporation loss	Time of gentle boil	Time of violent boil	Energy used	Minimum efficiency	Actual efficiency
	Ounces	*Min.*	*Min.*	*Watt-hrs.*	*Per cent*	*Per cent*
1200-T-A-1	1.500	16	29	327.0	50.3	80.8
1000-O-E-1	2.750	16	24	347.5	47.4	80.3
1100-S-C-1	1.750	18	24	357.5	46.0	73.9
1200-O-B-3	1.625	14	24	362.0	45.5	81.0
1000-O-E-3	1.250	22	18	367.0	44.9	81.0
1000-O-A-1	2.000	13	24	373.0	44.0	70.0
1200-T-A-3	1.500	22	22	376.0	43.7	80.8
1100-S-C-2	2.875	20	23	377.0	43.6	84.5
1000-S-E-1	3.000	13	27	381.0	43.1	74.2
1200-O-B-1	3.000	8	30	395.0	41.6	71.0
1000-S-E-3	1.375	22	17	402.5	40.8	71.8
1500-S-E-2	4.375	20	25	410.0	40.0	85.5
1000-O-A-2	3.000	7	27	412.0	39.9	74.0
1000-S-A-2	3.250	15	23	412.0	39.9	76.9
1500-O-E-3	1.500	11	33	415.0	39.6	74.0
1250-O-C-1	3.750	3	39	415.5	39.5	72.0
1000-O-A-3	1.125	17	20	422.5	38.9	66.5
1250-O-C-3	2.000	15	27	425.0	38.7	72.8
1500-S-E-1	2.750	7	38	427.0	38.5	67.0
1000-O-A-4	1.750	20	16	440.0	37.4	74.3
1500-O-E-1	3.000	8	37	442.0	37.2	65.7
1300-O-D-1	.500	17	26	444.5	37.0	54.8
1300Ba-D-1	1.750	18	25	447.5	36.7	59.3
2100-T-A-1	1.750	11	38	448.0	36.7	61.3
2100-T-A-2	2.250	22	26	455.0	36.2	70.2
1100-S-C-3	2.750	20	20	466.0	35.3	67.7
1500-S-E-3	6.000	23	21	472.5	34.8	81.0
1500-S-B-1	5.000	10	34	480.0	34.2	67.6
2250-S-B-2	6.000	20	28	484.5	34.0	79.8
2100-T-A-4	3.000	28	19	489.0	33.6	78.9
1300Ba-D-4	1.250	25	19	491.0	33.5	70.2
2000-O-C-4	2.000	8	38	491.0	33.4	75.5
1000-S-A-3	3.250	12	20	497.0	33.1	61.7
1300-O-D-4	1.500	31	13	505.0	32.6	68.7
2000-O-A-4	3.250	19	28	505.0	32.6	77.8
2000-S-A-2	7.250	8	38	524.5	31.4	77.6
2000-O-C-1	3.875	4	41	529.5	31.0	57.8
2000-O-A-2	5.000	8	38	545.5	30.1	67.2
1500-S-B-5	6.000	6	35	559.0	29.4	63.9
1500-S-B-3	6.875	15	25	586.0	28.1	66.6
2000-S-A-3	3.875	6	34	661.0	24.8	51.5
2250-S-B-3	8.000	7	38	666.0	24.6	64.0

[1] Explanation of designation: 1st column, watt rating of unit; 2nd column, type of unit where T is tubular, O is open, S is solid, and Ba is baffle; 3rd column, stove letter; and 4th column, pan number.

TABLE 16.—*Efficiencies for long-time tests—hot start*

Unit, stove, and utensil [1]	Evaporation loss	Time of gentle boil	Time of violent boil	Energy used	Minimum efficiency	Actual efficiency
	Ounces	*Min.*	*Min.*	*Watt-hrs.*	*Per cent*	*Per cent*
1500-S-B-1	8.750	10	43	181.0	90.5	223.4
1500-S-B-5	8.750	12	42	218.0	75.5	197.0
2250-S-B-2	14.500	13	42	260.0	63.4	212.5
1000-S-E-1	3.500	11	36	285.5	57.5	106.0
1000-O-A-1	2.250	10	33	290.0	56.6	94.8
1200-O-B-1	2.500	7	38	290.0	56.6	97.1
1000-O-E-1	1.750	15	30	301.0	54.6	89.3
1100-S-C-2	3.000	12	33	308.0	53.4	106.8
1200-O-B-3	2.000	6	39	308.0	53.4	104.0
1000-O-E-3	1.000	18	24	310.0	53.0	93.7
2000-O-A-2	4.750	5	46	312.5	52.6	120.0
1500-S-E-1	2.500	29	22	324.0	50.8	89.8
1500-S-E-2	5.500	6	43	325.0	50.6	118.0
1500-S-E-3	4.000	6	43	325.0	50.6	112.3
1200-T-A-1	2.500	24	21	326.0	50.5	86.6
1500-O-E-1	3.875	4	42	330.0	49.8	93.1
1100-S-C-3	1.500	22	23	335.0	49.2	91.3
1000-O-A-2	2.875	10	28	337.0	48.8	92.3
1000-O-A-3	1.000	19	20	344.0	47.8	82.2
1000-S-E-3	2.250	17	28	347.0	47.4	92.5
2100-T-A-1	2.750	23	28	350.0	47.0	84.4
1250-O-C-1	4.000	6	39	351.0	46.8	90.8
1200-T-A-3	2.250	20	24	352.0	46.6	90.0
1100-S-C-1	10.250	15	30	355.0	46.4	118.0
2000-O-A-4	3.500	19	32	355.0	46.3	116.0
1000-O-A-4	1.375	22	19	363.0	45.4	93.0
1000-S-A-3	3.500	13	27	365.0	45.0	90.8
2100-T-A-2	3.250	21	30	366.0	45.0	94.0
2000-S-A-3	8.750	0	48	372.0	44.2	120.8
1000-S-A-2	6.500	0	42	374.0	44.0	103.4
1300-O-D-1	.875	15	30	376.0	43.8	67.3
1500-O-E-3	3.000	17	30	380.0	43.4	89.3
1500-S-B-3	9.250	29	20	389.0	42.4	115.9
2000-S-A-2	6.000	5	45	390.0	42.1	101.2
1250-O-C-3	2.000	22	23	396.0	41.6	79.5
2250-S-B-3	2.000	11	40	396.0	41.5	84.2
2100-T-A-4	3.500	33	18	407.5	40.4	99.8
2000-O-C-1	4.250	14	35	419.0	39.2	76.2
1300Ba-D-1	1.125	17	27	422.0	39.0	60.6
2000-O-C-4	4.375	25	23	464.0	35.4	89.3
1300Ba-D-4	3.000	25	18	492.0	33.4	75.7
1300-O-D-4	3.125	6	40	492.0	33.4	79.6

[1]Explanation of designation: 1st column, watt rating of unit; 2nd column, type of unit where T is tubular, O is open, S is solid, and Ba is baffle; 3rd column, stove letter; and 4th column, pan number.

TABLE 17.—*Comparative time of heating, energy consumption, and minimum efficiency for 4 pounds of water,* COLD START, COVER ON

Pan 1			Pan 3			Pan 4		
Unit t	Unit w	eff	Unit t	Unit w	eff	Unit t	Unit w	eff
f-10.48	e-261	60.5	f-10.58	l-258	61.3	f-10.05	e-275	57.5
g-11.90	l-272	58.0	a-11.95	e-264	60.0	a-11.90	l-303	52.1
j-11.90	i-275	57.5	j-12.17	i-302	52.3	j-12.54	r-310	51.0
a-12-87	r-283	55.0	g-12.37	r-310	51.0	g-14.25	n-313	50.5
h-13.67	c-291	54.3	p-13.92	n-315	50.1	n-14.44	m-315	50.1
o-13.87	q-292	54.0	n-14.67	k-315	50.1	e-14.67	i-318	49.6
e-13.95	n-316	50.0	e-14.70	c-322	49.0	m-14.70	f-320	49.5
p-14.08	k-323	49.0	o-14.74	q-327	48.3	p-14.72	q-322	49.1
n-14.32	f-331	47.7	l-15.38	f-336	47.0	o-15.55	c-330	47.9
m-15.75	o-332	47.5	k-15.92	m-342	46.0	k-16.58	k-337	46.9
l-16.00	m-337	46.9	m-15.97	p-346	45.7	h-17.62	p-365	43.3
k-16.17	j-350	45.1	h-16.13	o-351	45.0	l-17.96	j-369	42.9
b-16.53	p-350	45.1	b-17.40	j-358	44.1	b-19.47	o-370	42.8
i-17.48	d-364	43.5	i-18.93	a-399	39.6	q-19.53	a-390	40.5
q-17.90	h-371	42.6	q-19.70	d-416	38.0	i-20.00	d-458	34.5
r-18.52	a-420	37.6	r-20.00	h-437	36.2	r-20.13	h-482	32.8
c-19.58	g-481	32.8	c-21.20	g-498	31.8	c-22.00	g-576	27.4
d-23.03	b-536	29.4	d-26.20	b-580	26.7	d-29.22	b-624	25.4
Pan 2			**Pan 6**			**Pan 5**		
Unit t	Unit w	eff	Unit t	Unit w	eff	Unit t	Unit w	eff
g- 9.42	l-264	60.0	f-12.00	q-348	45.4	f-12.50	e-282	56.0
f-10.65	r-315	50.2	g-12.20	o-375	42.1	e-16.00	q-315	50.1
a-13.00	c-326	48.5	a-14.13	f-380	41.5	h-16.00	c-349	45.3
b-13.60	o-332	47.5	h-14.73	h-401	39.4	q-18.88	f-393	40.2
j-13.85	e-333	47.5	j-15.60	p-430	36.8	k-20.15	k-399	39.6
o-13.92	f-337	46.9	o-15.70	j-460	34.3	n-23.03	d-432	36.6
p-14.48	d-352	45.0	p-17.37	a-463	34.2	c-23.52	h-437	36.2
l-15.67	p-357	44.3	b-17.44	n-467	33.8	d-27.00	n-503	31.4
e-19.00	i-375	42.1	q-20.82	g-490	32.2			
m-20.10	g-378	41.9	n-21.18	m-492	32.1			
r-20.47	j-404	39.2	m-23.07	b-556	27.9			
c-21.68	a-424	37.3						
d-22.45	m-434	36.4						
i-23.63	b-455	34.8						

Legend: a=2000 open, stove A; b=2000 solid, stove A; c=1000 open, stove A; d=1000 solid, stove A; e=1200 tubular, stove A; f=2100 tubular, stove A; g=2250 solid, stove B; h=1500 solid, stove B; i=1200 open, stove B; j=2000 open, stove C; k=1250 open, stove C; l=1100 solid, stove C; m=1300 baffle, stove D; n=1300 open, stove D; o=1500 solid, stove E; p=1500 open, stove E; q=1000 solid, stove E; r=1000 open, stove E. t=time in minutes; w=energy in watt-hours; eff=minimum efficiency.

TABLE 18.—*Comparative time of heating, energy consumption and minimum efficiency for 4 pounds of water,* HOT START, COVER ON

Pan 1			Pan 3			Pan 4		
Unit t	Unit w	eff	Unit t	Unit w	eff	Unit t	Unit w	eff
g- 3.53	g-141	112.0	g- 6.03	o-212	74.4	a- 6.80	q-211	74.5
f- 7.82	e-215	73.5	b- 8.35	r-216	73.0	g- 6.83	a-222	71.0
b- 8.77	l-218	72.5	f- 8.42	e-220	71.8	f- 7.40	c-223	70.9
h- 8.97	o-220	71.8	o- 8.82	i-225	70.2	b- 7.68	o-227	69.6
p- 9.98	d-226	70.0	j- 9.05	q-226	70.0	h- 8.45	h-230	68.6
a-10.55	q-232	68.1	a- 9.25	g-243	65.8	j- 9.22	i-233	67.9
j-10.72	r-233	68.0	p-10.65	l-244	64.8	o- 9.58	f-235	67.2
k-11.90	k-238	66.5	h-10.98	k-262	60.1	p-10.08	l-235	67.2
e-12.20	h-245	64.5	n-12.93	f-265	59.6	n-12.12	e-246	64.2
n-12.77	f-245	64.5	k-13.20	c-265	59.6	k-12.62	p-248	63.7
l-13.03	p-248	63.4	q-13.42	j-267	59.1	m-12.67	b-250	63.2
q-13.93	i-252	62.7	r-14.00	p-268	59.1	q-12.78	k-253	62.5
m-14.60	c-258	61.3	i-14.03	b-275	57.5	l-13.70	r-254	62.0
d-14.72	n-280	56.5	l-14.23	n-282	56.0	e-14.12	n-266	59.5
r-15.09	b-290	54.5	m-14.33	d-282	55.3	i-14.75	j-270	58.5
i-15.73	j-314	50.4	c-17.67	a-302	52.4	c-14.95	g-273	57.9
c-17.32	m-315	50.1	d-18.11	h-302	52.4	f-16.42	m-275	57.5
o-19.27	a-338	46.7	e-21.16	m-309	51.1	d-20.60	d-318	49.7

Pan 2			Pan 6			Pan 5		
Unit t	Unit w	eff	Unit t	Unit w	eff	Unit t	Unit w	eff
g- 2.75	g-112	141.0	g- 5.75	h-200	79.0	h- 5.45	h-148	106.8
b- 5.52	d-179	87.8	h- 7.32	o-223	70.8	f- 9.22	q-207	76.4
o- 8.40	b-180	87.8	b- 8.80	q-225	70.2	q-12.35	d-208	76.0
f- 8.42	o-201	78.6	f- 9.07	g-229	69.0	d-13.53	e-264	59.7
a- 8.73	l-226	70.0	o- 9.37	p-283	59.7	e-14.68	c-267	59.1
j- 9.75	r-252	62.5	a- 9.86	f-285	55.5	k-15.05	f-291	54.3
p-10.55	p-259	61.0	p-11.59	b-287	55.0	c-17.97	k-300	52.6
d-12.18	c-260	60.8	j-12.30	a-318	49.7	h-18.83	n-407	38.8
l-13.32	f-265	59.6	q-13.37	j-362	43.6			
e-14.67	e-275	57.5	n-18.63	n-402	39.2			
r-16.58	i-282	56.0	m-20.15	m-434	36.4			
m-17.52	a-284	55.5						
i-17.55	j-285	55.5						
c-17.55	m-380	41.6						

Legend same as for Table 17.

TABLE 19.—*Comparative time of heating, energy consumption and minimum efficiency for 4 pounds of water,* HOT START, COVER OFF

Pan 1			Pan 3			Pan 4		
Unit t	Unit w	eff	Unit t	Unit w	eff	Unit t	Unit w	eff
g- 3.78	g-152	104.0	g- 7.02	h-243	65.0	g- 6.10	p-235	67.2
b- 6.93	h-192	82.3	h- 8.87	q-247	63.9	f- 8.00	g-242	65.1
h- 7.08	d-198	79.5	j- 9.15	o-250	63.0	a- 9.05	q-243	65.0
f- 8.52	b-227	69.5	f- 9.23	c-257	61.5	h- 9.43	f-250	63.2
a- 8.57	o-228	69.4	a- 9.63	e-261	60.4	p- 9.52	o-255	62.0
o- 9.53	q-234	67.5	b-10.28	p-262	60.1	j- 9.57	h-257	61.5
p-10.96	e-239	66.0	o-10.43	k-262	60.1	b-10.17	c-278	56.9
j-11.80	k-248	63.7	p-10.53	r-263	60.0	o-10.61	j-280	56.5
d-12.62	i-253	62.5	k-13.07	j-271	58.3	n-14.38	e-280	56.5
k-12.70	l-259	61.0	a-14.62	g-282	56.0	q-14.58	a-293	54.0
e-13.39	r-263	59.6	e-14.70	l-285	55.5	m-14.67	k-304	52.0
m-13.80	f-267	59.1	q-14.82	i-286	55.3	k-15.50	m-310	51.0
n-14.00	p-272	58.0	m-16.03	f-290	54.5	e-15.73	i-312	50.6
q-14.08	a-278	56.9	l-16.76	d-302	52.4	c-18.42	n-314	50.4
l-15.52	c-287	55.0	r-16.93	a-313	50.5	l-19.12	d-319	49.5
i-15.72	n-305	51.8	c-17.00	n-320	49.4	i-19.50	l-321	49.2
r-17.27	m-335	47.1	i-17.95	b-332	47.5	d-20.31	b-332	47.6
c-19.13	j-346	45.7	d-19.37	m-345	45.8	r-21.75	r-335	47.1

Pan 2			Pan 6			Pan 5		
Unit t	Unit w	eff	Unit t	Unit w	eff	Unit t	Unit w	eff
g- 3.05	g-122	129.0	g- 4.65	g-186	85.0	h- 5.75	h-159	99.4
b- 6.02	b-197	81.1	h- 8.22	h-223	70.9	f-10.45	q-236	67.2
a- 8.72	o-229	69.0	b- 8.85	o-270	58.5	q-14.05	d-297	53.2
f- 9.47	d-237	66.6	f-10.47	b-290	54.5	e-17.17	e-320	49.4
o- 9.67	l-271	58.3	a-11.02	q-309	51.0	k-19.04	f-331	47.7
j-10.07	a-280	56.4	o-11.33	p-326	48.4	d-19.30	c-343	46.0
p-11.87	p-294	53.7	j-12.44	f-330	47.9	c-23.12	k-371	42.6
d-15.13	f-297	53.2	p-13.33	a-351	45.0	n-23.42	n-502	31.5
l-16.23	j-298	53.1	q-18.50	j-363	43.5			
e-19.40	c-308	51.3	m-w.n.b.					
c-20.58	i-337	46.9	n-w.n.b.					
i-21.32	e-345	45.8						
r-24.15	r-371	42.5						
m-26.10	m-559	28.3						

Legend same as for Table 17.

TABLE 20.—*Grouping of units relative to utensils for comparative time of heating and energy consumption*

COLD START, COVER ON — *Time* — Utensils

1	3	4	2	6	5
f	f	f	g	f	f
g	a	a	f	g	e
j	j	j	a	a	h
a	g	g	b	h	q
h	p	n	j	j	k
o	n	e	o	o	n
e	e	m	p	p	c
p	o	p	l	b	d
n	l	o	e	q	
m	k	k	m	n	
l	m	h	r	m	
k	h	l	c		
b	b	b	d		
i	i	q	i		
q	q	i			
r	r	r			
c	c	c			
d	d	d			

HOT START, COVER ON — *Time* — Utensils

1	3	4	2	6	5
g	g	a	g	g	h
f	b	g	b	h	f
b	f	f	o	b	q
h	o	b	f	f	d
p	j	h	a	o	e
a	a	j	j	a	k
j	p	o	p	p	c
k	h	p	d	j	n
e	n	n	l	q	
n	k	k	e	n	
l	q	m	r	m	
q	r	q	m		
m	i	l	i		
d	l	e	c		
r	m	i			
i	c	c			
c	d	r			
o	e	d			

HOT START, COVER OFF — *Time* — Utensils

1	3	4	2	6	5
g	g	g	g	g	h
b	h	f	b	h	f
h	j	a	a	b	q
f	f	h	f	f	e
a	a	p	o	a	k
o	b	j	j	o	d
p	o	b	p	j	c
j	p	o	d	p	n
d	k	n	l	q	
k	n	q	e	m	
e	e	m	c	n	
m	q	k	i		
n	m	e	r		
q	l	c	m		
l	r	l			
i	c	i			
r	i	d			
c	d	r			

COLD START, COVER ON — *Energy* — Utensils

1	3	4	2	6	5
e	l	e	l	q	e
l	e	n	r	g	q
i	i	l	c	f	c
r	r	r	o	h	f
c	n	m	e	p	k
q	k	i	f	j	d
n	c	f	d	a	h
k	q	q	p	n	n
f	f	c	i	g	
o	m	k	g	m	
m	p	p	j	b	
j	o	j	a		
p	j	o	m		
d	a	a	b		
h	d	d			
a	h	h			
g	g	g			
b	b	b			

HOT START, COVER ON — *Energy* — Utensils

1	3	4	2	6	5
g	o	q	g	h	h
e	r	a	d	o	q
l	e	c	b	q	d
o	i	o	o	g	e
d	q	h	l	p	c
q	g	i	r	f	f
r	l	f	p	b	k
k	k	l	c	a	n
f	f	e	f	j	
h	c	p	e	n	
p	j	b	i	m	
i	p	k	a		
c	b	r	j		
n	n	n	m		
b	d	j			
j	a	g			
m	h	m			
a	m	d			

HOT START, COVER OFF — *Energy* — Utensils

1	3	4	2	6	5
g	h	p	g	g	h
h	q	g	b	h	q
d	o	q	o	o	d
b	c	f	d	b	e
o	e	o	l	q	f
q	p	h	a	p	c
e	k	c	p	f	k
k	r	j	f	a	n
i	j	e	j	j	
l	g	a	c	m	
r	l	k	i	n	
f	i	m	e		
p	f	i	r		
a	d	n	m		
c	a	d			
n	n	l			
m	b	b			
j	m	r			

Legend same as for Table 17.

In order to compare more easily the different units with respect to time of heating and energy consumption, relative to the utensils used, the grouping of units as given in Tables 17, 18, and 19 is given in Table 20. This table shows, first, that for both cold and hot starts for all the utensils studied, the units having a high watt rating heated the same quantity of water through the same temperature change in much less time than the units having a small watt rating, and second, that in most cases the units having a small watt rating used the least energy while the units having a large watt rating used the most. An exception to the latter appeared for the hot starts on units that were able to store a large amount of heat. The desirable units to use may be easily selected from this table. The desirable units are those which heated the water rapidly with a small consumption of energy. Units which fulfill these requirements are found in the middle section of the groups. In general, they are the tubular and ring-type units.

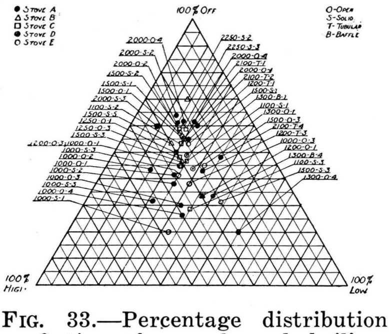

FIG. 33.—Percentage distribution of time for prolonged boiling, cold start.

Last number on notation denotes pan number.

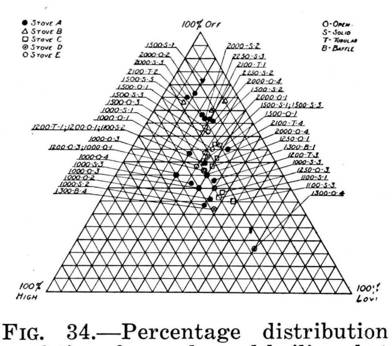

FIG. 34.—Percentage distribution of time for prolonged boiling, hot start.

Last number on notation denotes pan number.

Time distribution for long-time heating is shown in Figures 33 and 34. Triangular co-ordinates were chosen, for only one point was necessary to designate the time distribution for each test.[17] For long-time cooking the unit should be operated on LOW and OFF as much as possible, for the purpose of

[17] The vertices of the triangle denote the maximum conditions of 100% HIGH, 100% LOW, and 100% OFF while the bases opposite the vertices denote the conditions of 0% HIGH, 0% LOW, and 0% OFF respectively. A particular time distribution is given by the intersection of three co-ordinates. Point 12 on Fig. 34 may serve as an illustration. This point is at the intersection of 35% HIGH, 20% LOW, and 45% OFF. This point denotes the time distribution for the 1000 open unit of stove A used with pan 4. Hence for utensil 4 on the 1000 open unit of stove A the unit was on HIGH 35% of the time, on LOW 20% of the time, and on OFF 45% of the time.

TABLE 21.—*Grouping of units for various classes of time distribution for long-time processes—cold start*

Group I	Group II	Group III	Group IV	Group V	Group VI	Group VII
2250-S-B-2	2100-T-A-4	1500-S-E-2	1500-S-B-5	1200-O-B-1	1000-O-E-3	1300-O-D-4
2000-S-A-2	....	2000-O-C-4	1250-O-C-1	1300Ba-D-4	1000-S-A-2	1000-S-E-1
2100-T-A-1	....	1500-S-B-1	1250-O-C-3	1500-S-E-3	1000-S-A-3	....
2000-O-A-4	....	1500-O-E-1	1500-S-B-3	....	1000-O-A-3	....
2000-O-A-2	....	1200-T-A-1	1200-O-B-3	....	1100-S-C-3	....
2100-T-A-2	....	2000-O-C-1	1000-O-E-1	....	1000-O-A-4	....
2250-S-B-3	....	1500-S-E-1	1000-O-A-2	....	....	....
2000-S-A-3	....	1100-S-C-2	1000-O-A-1	....	....	....
....	....	1300Ba-D-1	1000-S-E-3	....	....	....
....	....	1100-S-C-1	....	....	....	....
....	....	1500-O-E-3	....	....	....	....
....	....	1300-O-D-1	....	....	....	....
....	....	1200-T-A-3	....	....	....	....

See Table 21A for explanation of designations.

TABLE 21A.—*Grouping of units for various classes of time distribution for long-time processes—hot start*

Group I	Group II	Group III	Group IV	Group V	Group VI	Group VII
1500-S-B-1	2000-O-C-1	1000-S-E-1	1000-O-A-4	1250-O-C-3	1000-S-A-2	1300-O-D-4
2000-O-A-2	1500-S-E-1	1000-O-A-1	1000-S-A-3	1100-S-C-1	....	....
2000-S-A-3	1500-S-E-3	1300-O-D-1	1000-O-A-3	1000-O-A-2	....	....
2250-S-B-2	2100-T-A-4	1200-T-A-1	....	1100-S-C-3	....	....
1500-S-B-5	1500-O-E-3	1200-O-B-1	....	1300Ba-D-4	....	....
2250-S-B-3	2000-O-C-4	1100-S-C-2	....	....	....	....
2100-T-A-2	....	1250-O-C-1	....	....	....	....
2100-T-A-1	....	1000-O-E-3	....	....	....	....
2000-S-A-2	....	1200-O-B-3	....	....	....	....
2000-O-A-4	....	1000-O-E-1	....	....	....	....
1500-O-E-1	....	1300Ba-D-1	....	....	....	....
1500-S-E-2	....	1200-T-A-3	....	....	....	....
1500-S-B-3	....	1000-S-E-3	....	....	....	....

Explanation of designation: 1st column, watt rating of unit; 2nd column, type of unit where T is tubular, O is open, S is solid, and Ba is baffle; 3rd column, stove letter; and 4th column, pan number.

Group 1—OFF 60% or greater; Group II—OFF from 40% to 60%, HIGH less than 20%. Group III—OFF from 40% to 60%, HIGH from 20% to 30%. Group IV—OFF from 40% to 60%, HIGH greater than 30%. Group V—OFF from 20% to 40%, HIGH less than 30%. Group VI—OFF from 20% to 40%, HIGH greater than 30%. Group VII—OFF less than 20%.

utilizing stored heat. When the time distributions are grouped in different classes as shown in Tables 21 and 21A the units are again found to fall in a descending order of watt rating. The units of high watt rating were operated on LOW and OFF the greater percentage of the time, while the units of low watt rating were operated on HIGH and LOW the greater percentage of the time. However, the data in Tables 15 and 16 show that the energy consumption was greatest for units of high watt rating and smallest for units of low watt rating. From the point of view of economical operation, units of low watt rating should be used whenever possible.

TABLE 22.—*Temperature of the open unit heating wires measured with the optical pyrometer*

Stove	Unit	Bright-bottomed pan	Black-bottomed teakettle	Uncovered unit
		Degrees F.	*Degrees F.*	*Degrees F.*
A	1000 open	1647	1520	1506
	2000 open	1801	1635	1607
B	1200 open	1604	1483	1488
C	2000 open	1686	1584	1560
	1250 open	1677	1544	1503
D	1300 open			
	Reflector removed	1561	1578	1560
	Deteriorated reflector	1823	1688	1638
	Polished reflector	1821	1670	1605
	Blackened reflector	1602	1592	1542
E	1500 open	1804	1559	1549
	1000 open	1810	1640	1640

The efficiency data show that there was a great difference in the efficiencies for units of the same type. A consideration of the temperature of the various heating elements does not account for the difference in efficiencies. The temperatures of the open-unit heating wires as measured with the optical pyrometer and the temperatures of the solid heating units as measured by the iron-constantan thermocouple are given in Tables 22 and 23. The results show that the temperatures of the open heating wires were nearly the same for each unit studied. The temperatures of the solid-unit elements having a high watt rating would lead one to predict for them a higher efficiency than for those of low watt rating. However, the results of the efficiency tests show that such was not the case. Aside from showing the maximum temperatures obtained for each element these data proved to be of little importance. To determine what becomes of the heat which is lost, temperatures were measured at various places in the wiring compartment and at several locations on the cooking top. The results obtained are presented in Tables 24, 25, and 25A. These tables indicate that much heat was dissipated into the wiring compartment and the cooking top. Temperatures in the wiring compartment show that more heat was lost from the units on

TABLE 23.—*Temperatures of surface units measured with an iron-constantan thermocouple*

Stove	Unit	Temperature of surface
		Degrees F.
A	2000 solid	1572
	1000 solid	1361
	1200 tubular	1093
B	1500 solid	1448
	2250 solid	1708
C	1100 solid	1493
E	1500 solid	1475
	1000 solid	1193

TABLE 24.—*Average temperatures in wiring compartment*

Stove	Unit combination	Maximum temperature at steady state	
		2″ from bottom	4″ from bottom
		Degrees F.	*Degrees F.*
A	1,000 open, 2,000 open, 2,000 solid	117	142
	1,000 open, 1200 tubular, 2100 tubular	117	134
B[1]	1500 solid, 2250 solid, 1200 open	104	115
C	1100 solid, 2,000 open, 1250 open	249	254
E	1500 solid, 1500 open, 1,000 solid, 1,000 open	118	143

[1] Maximum temperature of tray 232° F.

TABLE 25.—*Maximum surface temperatures on cooking top—average room temperature 75° F.*

Location of couples	Stove A		Stove B	Stove C	Stove E
	With 1000 open, 1200 and 2100 tubular units on HIGH	With 1000 and 2000 open and 2000 solid on HIGH	With all units on HIGH	With all units on HIGH	With all units on HIGH
	Degrees F.	*Degrees F.*	*Degrees F.*	*Degrees F.*	*Degrees F.*
Center	279	319	395	311	272
Right front corner	......	......	249	187	179
Left front corner	......	......	198	187	155
Right back corner	174	173	241	......	......
Left back corner	165	164	234	......	......
Center of front edge	184	196	273	283	167
Center of side edge	177	170	222	162	86

TABLE 25A.—*Maximum temperatures on cooking top of stove D when only one unit is on* HIGH—*average room temperature 75° F.*

Location of couple	Left front unit on HIGH	Right front unit on HIGH
	Degrees F.	*Degrees F.*
Directly in front of unit on cooking top	......	367
Left front corner of wiring compartment top	253	163
Switch knob	147	150
Center of cooking top	198	......
Left back corner of cooking top	......	95
Midway between left front and back units on wiring compartment top	125	......

stove C than from any of the other units, and also that the "1,000 watt open—1,200 watt tubular—2,100 watt tubular" is a better combination of units for stove A than the "1,000 watt open—2,000 watt open—2,000 watt solid" combination. A temperature of 725° F. was found for the reflector of the unit on stove D, showing that a great amount of heat was lost from this unit by radiation and convection. This temperature indicates why the cone and reflector unit was so inefficient for hot starts. Because of the position of the tray underneath the heating units of stove B, much of the heat lost from these units was dissipated from the cooking top. These results are a rough check of the efficiency results, because temperatures in the wiring compartment and on the cooking top were least for combinations of the most efficient units.

CONCLUSIONS

From the results of the efficiency and comparative time of heating data and the heat-loss temperature data the following conclusions may be drawn:

1. The efficiency of surface units depends upon: (a) the power rating of the unit, (b) the type of unit, (c) the initial condition of the unit, (d) the quantity of water used, (e) the kind of utensil, (f) the size of the utensil bottom with relation to the size of the unit, (g) the exterior surface area of the utensil exposed to the air, and (h) the use of a cover on the utensil.

2. Units having small watt ratings were more efficient than units having large watt ratings.

3. If the time of heating is the important factor to consider, units of high watt ratings should be used.

4. When a compromise between time of heating and efficiency must be made, the tubular and ring units are the most desirable for both cold and hot starts.

5. The open units of stove E were more efficient than the open units of the other stoves studied.

6. The units of stove D were efficient for short-time processes when started cold, but for all other processes they were inefficient when compared with the other types of units.

7. The solid cast units were inefficient for cold starts but for long-time processes these units were very efficient.

8. The utensils should have straight side walls, should not be too high, and should be of a size to fit the unit exactly. The cover should make good contact with the side walls.

9. For short-time processes either enameled pans or black-bottomed aluminum pans should be used on open and tubular or ring-type solid units. For all solid cast units, aluminum pans with bottoms making good contact with the unit should be used.

10. For all long-time processes aluminum pans should be used regardless of the type of unit.

PART II—OVENS

Of the available reports, that from the Bureau of Standards (see page 5, footnote 4) is the only one recording attempts to determine the actual efficiency of ovens. These investigators tried two methods of determining the efficiency, but both methods are open to criticism. Using the same methods, the authors obtained results similar to those of the Bureau of Standards.[18] Another method tried by the authors proved a failure. Briefly, the test was as follows. It is obvious that if a mass of water, the water equivalent of a container, and the desired temperature change of the water were known, the output could be computed. If the time required to produce the desired temperature change could be found, the maintenance rate for the empty oven could be increased to compensate for the energy required to heat the water. By this method it should be possible to keep the oven at a constant temperature. The great difficulty, however, is to determine the required time. Since the actual efficiency seemed impossible to obtain by this method, a different theory was developed and tests performed to determine the *inefficiency* of the ovens. The results are explained in the following pages.

THEORY

The assumption may be made that the same test body can be raised from the same initial temperature to the same final temperature in each oven. Hence the output would be the same for each oven. On this assumption the input could be calculated from the simple formula: Input = output + heat loss, where heat loss is composed of, (1) the energy necessary to preheat the oven, (2) the energy lost by radiation and convection from the exterior surface of the oven, and (3) the energy lost when the oven door is opened. Since the output is assumed constant, the heat loss should be an indication of the relative merits of each oven. The factors which determine

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[18] The success of the first method depended upon the measurement of oven temperatures when a cold body was placed in a hot oven. Obviously a temperature gradient is established between the oven walls and the test body; so more than the required energy to heat the body is necessary to keep the oven at the desired temperature. Hence the oven-air temperatures as measured for this method are too high.

In the second method a maintenance rate was determined that would just keep the empty oven at the desired temperature. Using this maintenance rate, the cold test body was introduced into the oven and left there until it had been heated through a definite temperature change. Knowing the maintenance rate for the empty oven and the loss from opening the door, it was possible to compute the efficiency. However, this method is open to the criticism that as soon as the cold test body is introduced, the oven air temperature drops. Hence the computed efficiency is not the efficiency of the oven at the temperature at which the maintenance rates were determined.

the amount of energy necessary to preheat an oven to a desired temperature are: dimensions, insulation, size of the heating coils, and thermal capacity of the inside.

As soon as the temperature of the air within the oven becomes greater than that of the air outside the oven, heat begins to flow from the inside to the outside of the oven. Hence for both the preheating and the maintenance of an oven at a constant or average oven air temperature there is involved a transmission of heat from the inside to the outside of the oven for both steady and unsteady conditions.[19]

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[19] The fundamental laws of heat transmission were developed by the French physicist Peclet and published in his *Traité de la chaleur* in 1853. The type of transmission that must be considered here is one where heat must pass through materials and also be dissipated from a number of surfaces by radiation and convection with only the temperatures at the extreme transfers being known. A complete development of the formula used will be found in Kent's "Mechanical Engineers' Handbook" in the section on Heat Insulation. A brief summary of the laws and mathematics involved is as follows: Assuming that the state of steady heat flow has been obtained, the calculation of the heat transmitted depends upon the fact that the total flow of heat computed at any section perpendicular to the direction of flow must be equal to the total flow at any other section. For combined conduction and surface effects, the equations involved are

$$H=S\int_{T_2}^{T_1} f(t)\,dt$$

where H is the heat transmitted per unit of time, S is a shape factor involving area and thickness, T_1 and T_2 are the temperatures of the two surfaces, and f(t) is the coefficient of heat conduction if it varies with temperature.

$$H=E(T_2-T_0)$$

where H is the heat transmitted per unit of surface area, T_2 is the surface temperature, T_0 is the air temperature and E is a factor expressing the total transfer of heat per unit area, per degree difference in temperature, per unit of time.

$$H=S(T-T')$$

where H is the heat flowing per unit area, T is the temperature of the hot surface and T′ is the temperature of the cold surface confining the air, and S is the air space coefficient expressing the flow of heat per unit area per unit time per degree difference in temperature.

For flat parallel plates the shape factor S is $\frac{A}{B}$ where A is the area and B the thickness; hence the flow of heat per unit area through the wall in Figure 35 may be written as:

$$H=E_1(T-T_1)=\frac{C_1}{B_1}(T_1-T_2)=\frac{C_2}{B_2}(T_2-T_3)=S(T_3-T_4)=\frac{C_3}{B_3}(T_4-T_5)=E_2(T_5-T_0)$$

If U=the over-all transmission coefficient in heat transmitted per unit of area per unit of time per degree of difference in temperature between hot and cold air, then the equations are:

$$U=\frac{1}{\frac{1}{E_1}+\frac{B_1}{C_1}+\frac{B_2}{C_2}+\frac{1}{S}+\frac{B_3}{C_3}+\frac{1}{E_2}}$$

or in general $H=U(T-T_0)$

$$\text{where}\quad U=\frac{1}{\Sigma\left(\frac{1}{E}\right)+\Sigma\left(\frac{1}{S}\right)+\Sigma\left(\frac{B}{C}\right)}$$

Values of the various surface temperatures may be found from the equations:

$$T_1=T-\frac{H}{E_1};\ T_2=T_1-\frac{HB_1}{C_1};\ T_3=T_2-\frac{HB_2}{C_2};\ T_4=T_3-\frac{H}{S};\ T_5=T_4-\frac{HB_3}{C_3};\ T_0=T_5-\frac{H}{E_2}$$

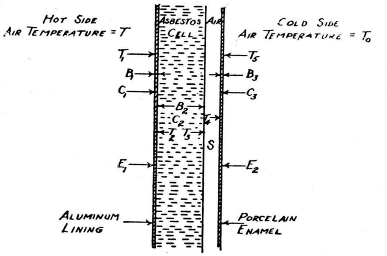

FIG. 35.—Oven wall of stove E.

T_1=temp. of hot side of lining. T_2= temp. of cold side of lining and temp. of hot side of insulation. T_3=temp. of cold side of insulation. T_4=temp. of hot side of outside wall. T_5=temp. of cold side of outside wall. B_1=thickness of lining. B_2=thickness of insulation. B_3=thickness of outside wall. C_1=coefficient of conduction of lining. C_2=coefficient of conduction of insulation. C_3=coefficient of conduction of outside wall. E_1=transmission coefficient of hot side. E_2=transmission coefficient of cold side. S=air space coefficient.

Figure 35 represents the oven wall of stove E. This wall was chosen as an example because all of the coefficients that must be considered as the heat passes from the hot interior to the outside air are involved. Assuming that the steady state has been reached, if H is the heat transmitted at right angles to the wall per unit of area per unit of time, T the air temperature on the hot side, and T_0 the air temperature on the cold side, the relation between the heat transmitted and temperature is given by the equation:

$$H = U\,(T - T_0) \qquad (4)$$

where U is the over-all transmission coefficient.

The value U is composed of the conduction coefficients, C; the surface transmission coefficients, E; the air space coefficients, S; and the thickness values, B. The relation of the coefficients to U for any combination of parallel materials is given by the equation:

$$U = \frac{1}{\Sigma\left(\frac{1}{E}\right) + \Sigma\left(\frac{1}{S}\right) + \Sigma\left(\frac{B}{C}\right)} \qquad (5)$$

The actual value of U is not easily found, for the three coefficients E, S, and C are functions of temperature. Since the coefficient of surface transmission, E, is the sum of radiation and convection it varies with the kind of material, with the temperature, with the difference in temperature, and with the freedom of air circulation. The air space coefficient, S, is even more complicated, for it is the sum of the conduction, convection, and radiation. B is the only value which may be easily determined. If all the coefficients involved in equation 5 could be determined for each part of the oven the preheating energy and the radiation and convection loss energy could be computed. The exterior surface temperatures listed in Tables 26 and 26A indicate why the determination of these coefficients would be difficult. These tables show that the heat is not transmitted equally through each wall and since the coefficients are functions of temperature they would vary for different sections of the oven. However, despite the fact that these coefficients were not determined, equation 5 may be successfully used to explain some of the results obtained.

TABLE 26.—*Maximum exterior oven temperatures for the steady state. Average room temperature 77° F.*

Portion of oven	Location of couple	Stove A	Stove B	Stove C	Stove E
		Degrees F.	*Degrees F.*	*Degrees F.*	*Degrees F.*
Oven top	Front corners, 2 in. from edge	124	120	114	115
	Back corners, 2 in. from edge	107	116	112	114
	Mid-point, 2 in. from front edge	135	126	125	126
	Mid-point, 2 in. from back edge	......	124	121	128
	Mid-point, 2 in. from right edge	130	121	......	121
	Center of top	117	108	105	113
	Mid-point of right edge	110	114	106	125
	Mid-point of left edge	112	118	108	121
	Mid-point of front edge	147	159	......	190
Sides	Center of outside	112	115	121	112
	Center of side facing cooking top	117	112	118	138
	Mid-point of outside, 3 in. from vertical edge	129	127	126	130
	Right vertical edge	169	171	......	175
	Left vertical edge	149	142	......	175
Oven door	Center	133	182	129	133
	Mid-point of the rim at top	222	188	179	173
	Mid-point of the rim at bottom	175	178	125	156
	Handle	163[1]	138[1]	121	......

[1] Metal trim of handle.

TABLE 26A.—*Maximum exterior oven temperatures on stove D for the steady state—average room temperature 77° F.*

Location of couples	Temperature
	Degrees F.
Center of outside	173
Mid-point of lower outside edge	121
Mid-point of upper outside edge	170
Back vertical edge, level with cooking top	138
Center of top	181
Center of door	163
Plating on door	183
Junction between door and oven	280

EXPERIMENTAL PROCEDURE

The preheating energy, the radiation and convection loss energy, and the energy lost due to opening the door are easily found by experiment. The specific problem is to compare five ovens which differ in size, type of lining, type of heating element, thickness of walls, kind of insulation, exterior finish, and type of thermostat. With these differences in mind the following set of tests were developed.

Schedule of tests.—1. Determine the energy and time necessary to preheat the empty oven to 250°, 300°, 350°, 400°, 450°, 500°, and 550° F. for both closed and open vent.

2. Determine the time rate of cooling of the empty oven from 500° F. for both closed and open vent.

3. Determine the empty oven heat loss for steady conditions for both closed and open vent.

4. Determine the heat loss of the empty oven for closed vent when the door is opened.

5. Calibrate the thermostat and determine its sensitivity with the oven empty at 250°, 300°, 350°, 400°, 450°, 500°, and 550° F.

6. Determine the uniformity of temperature of the oven air.

Method of tests.—Copper-constantan couples were used to measure all oven temperatures. During the test three exterior temperatures were recorded: (1) on the rim of the oven door, except for stove D where the couple was secured to the rolled edge, (2) at the center of the outside wall, and (3) at the center of the top. The couples were fastened with a strip of adhesive tape about 6 inches long. About five inches of the couple was kept in contact with the hot body so that conduction of heat from the couple tip would be reduced to a minimum. For tests 1 to 5, five couples in parallel were used to measure the oven air temperature. A couple was placed at each corner of the oven about two inches from each wall and one couple was placed at the center. The couples were arranged so that each tip was in the mid-plane of the oven. For all stoves except D, unshielded couples were used when the ovens were heated only by the lower unit. In order to measure the air temperature of stove D the couples were shielded as a protection from the absorption of radiant energy from the unit. They were likewise shielded when the upper units of the other ovens were used. Several methods of shielding were tried but the best results were obtained with the shield shown in Figure 36. Unless the couples were carefully insulated from the rack from which they were suspended, it was found that the rack sometimes became part of the couple circuit. Glass tubing was used to prevent this. The temperature distribution of test 6 was measured by fifteen couples arranged in three planes with five couples in each plane. A couple was placed at each corner about two inches from each wall with the remaining couple placed at the center. The lower plane was from one to 1½ inches above the baffle,

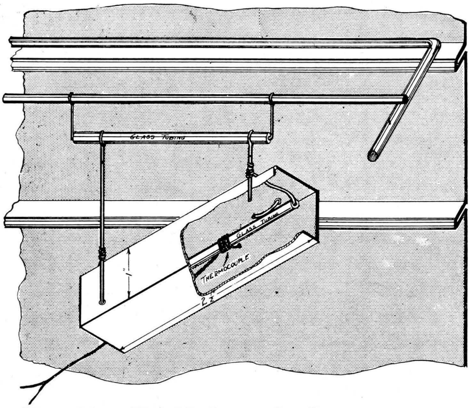

FIG. 36.—Shielded couple for oven test.

the center plane was the mid-plane of the oven, and the upper plane was about three inches from the top.

1. *Preheating tests.*—With both units on HIGH, at a constant potential of 220 volts, and with the oven started cold, energy and temperature readings were recorded every two minutes until the maximum thermostat reading was obtained. The maximum for stoves A, B, and E was 550° F.; for stove C, 500° F.; and for stove D, 600° F. As the temperature passed through 250°, 300,° 350°, 400°, 450°, and 500° F., energy and time were recorded. Thus with a single heating the energy and time necessary to preheat an oven were found. This was the only test that required shielded couples for all ovens. From six to eight tests were made for each oven and the average used for plotting curves.

2. *Rate of cooling.*—The time rate of cooling was determined by heating the oven to 550° F., using only the lower unit. With the unit OFF the temperature was recorded as the oven cooled. During the first period of cooling, temperatures were recorded every two minutes, but as the temperature difference between readings became less the time was extended successively to 5, 10, and finally to 15-minute intervals. For stoves having adjustable vents, cooling data were obtained for both closed and open vent.

3. *Oven heat loss.*—By adjusting the voltage, an input was found which would keep the oven air temperature constant to within 1 degree from one to two hours after the oven had reached the steady state. Usually two hours were required to obtain equilibrium conditions. The heat loss was determined at 300°, 400°, and 500° F. for both closed and open vents. From the consumption of energy and the time of the test, the heat loss in watts was computed. During this test and the test following, the three exterior oven temperatures previously mentioned were recorded. To obtain comparable results the room temperature was kept constant to within one degree. The room temperature chosen was 77° F.

4. *Open-door loss.*—This test was more difficult than the heat-loss tests, for equilibrium conditions could not be maintained. The open-door test was made immediately following the heat-loss test. To compensate for the heat loss due to opening the door it was necessary to increase the input slightly. The oven door was opened for 20 seconds at five-minute intervals. The voltage was adjusted until an input was found that would keep the average temperature constant for at least one hour. From the known energy consumption and the time of the test, the open-door loss was computed.

5. *Calibration of the thermostat.*—A calibration was begun after the oven was heated to the highest thermostat setting. The thermostat was allowed to operate through four cycles before resetting and cooling to the next thermostat temperature. Energy and temperature were recorded at two-minute intervals and at each OFF and ON of the unit. For all calibration tests the potential was held constant at 220 volts. Time for the short ON and OFF periods was recorded with a stop watch, while the Elgin watch was used to record the total time. The thermostats were calibrated at 250°, 300°, 350°, 400°, 450°, 500°, and at 550° and 600°F. where possible.

6. *Temperature distribution.*—The temperature distribution within the oven was measured after equilibrium conditions were established. The inputs determined in the oven-heat-loss tests were used to keep the ovens at 300°, 400° and 500° F. The five couples in the mid-plane were used to measure the average oven temperature. Temperatures for each thermocouple were read at five-minute intervals until the average temperature had remained constant to within 1 degree for at least one hour. The temperature at a particular location was determined by taking the average of the readings recorded while the average temperature remained constant.

RESULTS

The energy and time necessary to preheat the various ovens are shown in Figures 37 and 38. The small energy consumption and the short time required to preheat stove D are the result of two factors, (1) the power input was less than two-thirds the input of the other stoves, and (2) the thermal capacity of the insulation and the inside was small. Stove B required the most energy because of the large porcelain heating blocks which greatly added to its thermal capacity. It will be noted that at first the energy required for stove E was greater than the requirement of stoves A and C, but at about 225° F. the curve drops in between the curves of

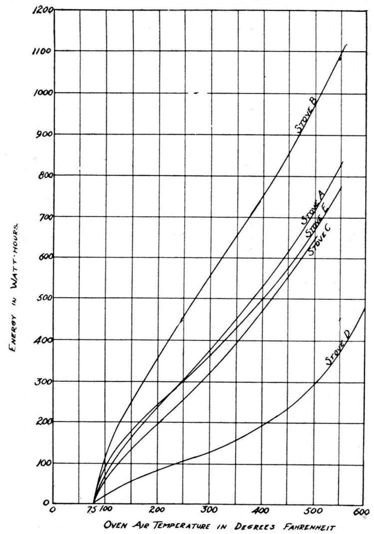

FIG. 37.—Preheat energy for ovens.

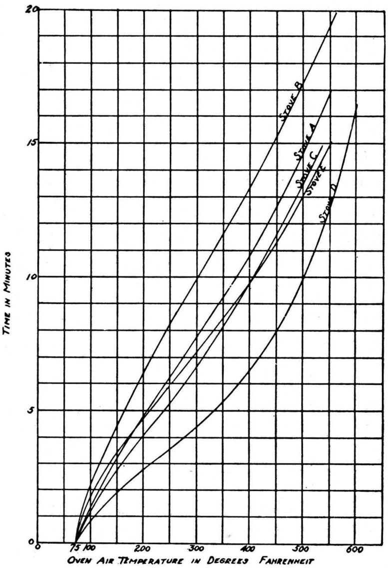

FIG. 38.—Preheating time as a function of oven air temperature.

stoves A and C. The large amount of metal surrounding the lower unit probably accounts for this increase in energy at low oven-air temperature. Also, since for preheating part of the heat transmitted is in the form of radiant energy of short infra-red and long visible wave lengths, the surface transmission coefficients E played a prominent part in the absorption of energy by the lining. Assuming that the convection part of the coefficient is about the same for each oven, it would follow that the coefficient E would be less for stoves D and E because of the bright surface of their linings.

The total heat loss for the steady state for the various ovens plotted against oven-air temperature is shown in Figure 39. However, because of the oven differences previously listed the total-heat-loss curves do not serve as a comparison of the five ovens. In order to reduce the ovens to a common basis the total heat loss was divided by the inside oven area in square feet. This calculation assumes that the flow of heat is the same through each wall, and although this is not true, the results obtained can be explained approximately by using equation 5 (page 46) if all comparisons are made at the same oven air temperature. The heat loss per unit of area is shown in Figure 40. Ovens A, B, and C, which were similar in construction, will be considered first. They had the same

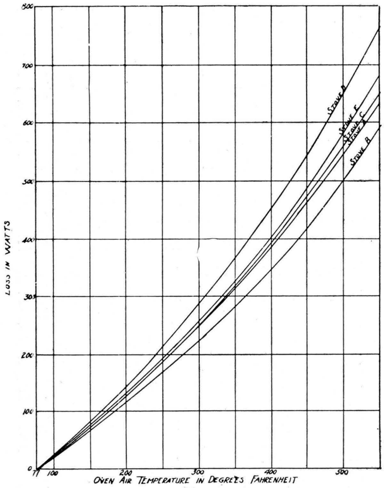

FIG. 39.—Oven heat loss for empty oven for steady state.

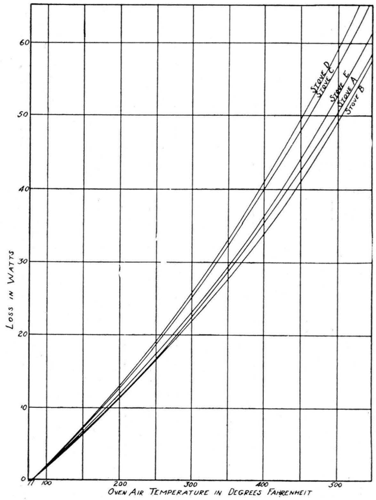

FIG. 40.—Oven heat loss per square foot of inside surface.

kind of oven lining, the same kind of insulation, and the same kind of exterior surface. Oven A had a chromium-plated rim around the door, while ovens B and C had porcelain enamel doors. At the back of ovens A and B there was an air space between the insulation and the outside wall. The side wall thicknesses were 2⅛, 1¾, and 2 inches respectively for ovens A, B, and C. Although the coefficient of conductivity of mineral wool varies with the density of packing, namely from 0.26 (density 6 lb. per cu. ft.) to 0.29 (density 18 lb. per cu. ft) the packing for each stove may be considered as constant without introducing much error. For ovens A, B, and C,

$$U = \frac{1}{\frac{1}{E_1} + \frac{1}{E_2} + \frac{B_1}{C_1} + \frac{B_2}{C_2} + \frac{B_3}{C_3}} \quad (6)$$

for all walls except the back of ovens A and B. For the backs of ovens A and B,

$$U = \frac{1}{\frac{1}{E_1} + \frac{1}{E_2} + \frac{1}{S} + \frac{B_1}{C_1} + \frac{B_2}{C_2} + \frac{B_3}{C_3}} \quad (7)$$

where E_1 = surface transmission coefficient of lining
E_2 = surface transmission coefficient of outside wall
B_1 = thickness of lining
B_2 = thickness of insulation
B_3 = thickness of outside casing

C_1 = coefficient of conduction of lining
C_2 = coefficient of conduction of insulation
C_3 = coefficient of conduction of outside casing
S = air space coefficient.

Of these factors B_1, B_3, C_1, and C_3 may be considered as constant, leaving E_1, E_2, B_2, C_2, and S to explain the differences between the ovens. It is obvious that any increase in E, C, or S will increase U, and any increase in B will decrease U. Since the same insulation is used in each stove, C_2 may be disregarded. The exterior oven temperatures given in Table 27 are about the same for each stove, so E_2 may be

TABLE 27.—*External surface temperatures of ovens for heat-loss tests*

Stove	Position of couple	Temperature setting			
		300	400	500	600
		Degrees F.	*Degrees F.*	*Degrees F.*	*Degrees F.*
A	Rim of door	146.4	176.2	207.0	....
	Center of side	92.4	102.2	114.0	....
	Center of top	95.5	104.1	116.2	....
B	Rim of door	126.2	149.2	172.4	....
	Center of side	94.6	103.4	113.3	....
	Center of top	94.9	99.0	107.6	....
C	Rim of door	130.6	153.4	179.0	....
	Center of side	95.9	105.2	114.1	....
	Center of top	91.9	98.3	105.2	....
D	Rolled edge of door	116.8	141.0	165.9	184.9
	Center of side	109.1	132.5	155.1	172.6
	Center of top	114.9	139.9	163.5	181.6
E	Rim of door	122.0	143.9	170.8	....
	Center of side	91.5	101.7	111.1	....
	Center of top	94.6	103.5	112.5	....

Average room temperature 77.5° F.

omitted. This leaves only E_1, B_2, and S. Again the curves show that stove B, which had the smallest value of B_2, had the smallest heat loss per unit of area, and also the smallest total heat loss. It is doubtful that the coefficient S had much to do with this small heat loss, for the air space was so wide that heat could easily have been transferred to the outer surface by convection. For stove C the explanation is un-

TABLE 28.—*Vent loss in watts for empty oven for equilibrium conditions*

Oven air temperature	Stove B	Stove C	Stove E	Room temperature
Degrees F.	*Watts*	*Watts*	*Watts*	*Degrees F.*
300	9	33.0	9	77.5
400	6	49.5	14	77.5
500	3	78.0	18	77.5

doubtedly tied to the coefficient E. Investigation disclosed a large crack between the door and the oven face. This allowed air from the outside to circulate through the oven, thus increasing the convection currents, which increased E and also allowed heat to escape through the same crack. It will also be noted in Table 28 that when the vent was open, the vent loss was large for this oven. The vent loss was the difference between the total heat losses for open and closed vent tests. Here is an example of an oven that had excellent insulation, well packed and thick, and the desired result was lost because of poor door construction. Probably the greater heat loss of stove A may also be attributed to faulty door construction. In this case it was due to careless packing of the insulation. Under the inner casing two large pockets were found where the insulation was not greater than ½-inch thick. As shown in equation 6, a decrease in the value of B increases U, which in turn increases H.

The oven of stove E was well constructed. The door was tight-fitting with a broad chromium-plated rim which helped to decrease the heat loss. The oven lining was bright aluminum, so the coefficient E_1 should have been less than the corresponding coefficient of stoves A and B. Its wall thickness was 2¾ inches with a half-inch air space between the insulation and the outer shell; hence this larger value of B_2 should decrease U as compared to stove B. The great difference in the ovens was the insulation. The asbestos-cell used in oven E has a conductivity coefficient which is almost twice as large as the coefficient of mineral wool and it was this larger value of C which accounted for the higher heat loss.

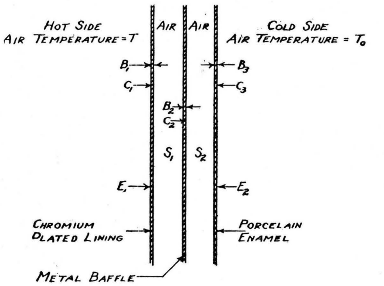

FIG. 41.—Oven wall of stove D.

E_1=transmission coefficient of lining. E_2=transmission coefficient of outer wall. B_1=thickness of lining. B_2=thickness of baffle. B_3=thickness of outer wall. C_1=conductivity coefficient of lining. C_2=conductivity coefficient of baffle. C_3=conductivity coefficient of outer wall. S_1 and S_2 =air space coefficient.

The oven wall of stove D is shown in Figure 41. The value of U for this oven is:

$$U=\frac{1}{\frac{1}{E_1}+\frac{B_1}{C_1}+\frac{1}{S_1}+\frac{B_2}{C_2}+\frac{1}{S_2}+\frac{B_3}{C_3}+\frac{1}{E_2}} \qquad (8)$$

where the important coefficients are E_1, E_2, S_1, and S_2.

Since the values for B_1, B_2, B_3, C_1, C_2, and C_3 are practically the same as for stoves A, B, C, and E, these coefficients may be neglected. E_1 will have a value near that of E_1 for stove E but E_2 will be higher than the corresponding coefficients for the other stoves because of the higher external wall temperatures shown in Table 27. However, the loss must have been due to the coefficients S_1 and S_2. Of the three modes of transfer involved in these coefficients, radiation, conduction, and convection, convection probably played the prominent role. Each air space was about ½ inch wide and since the space was not broken there was an excellent opportunity for circulation of air currents. It is probably by this method that most of the heat was transferred from the interior to the outside.

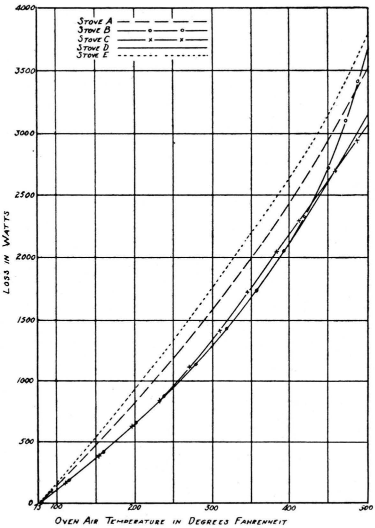

FIG. 42.—Heat loss when oven door was opened.

The heat loss in watts when the oven door was opened is shown in Figure 42. The accuracy of the data for these curves depends upon the accuracy of the total heat-loss data. Knowing the energy consumed when the door was opened for 20 seconds at five minute intervals and the total heat loss at the same oven air temperature, one can compute the loss due to opening the oven door from the formula:

$$\text{Heat loss in watts} = \frac{900A}{t} - 15\ B \qquad (9)$$

where A is the watt-hours recorded for the open-door test, t is the time of A in minutes, and B is the total heat loss in watts at the same oven-air temperature as for A.

Although the ovens were in the unbalanced state for this sort of test, it is the opinion of the authors that the results obtained are of the right magnitude and occur in the proper order. Because of its larger opening it would be expected that oven E would have the greatest loss. Probably the large mass of porcelain block helped to keep the loss of oven B low at the low temperatures, even though its opening was the same as

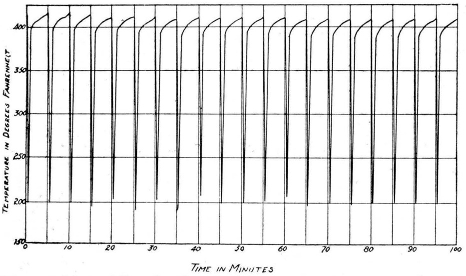

FIG. 43.—Variation of oven temperature at 400° F. with time when door was opened for 20 seconds at 5-minute intervals for stove E.

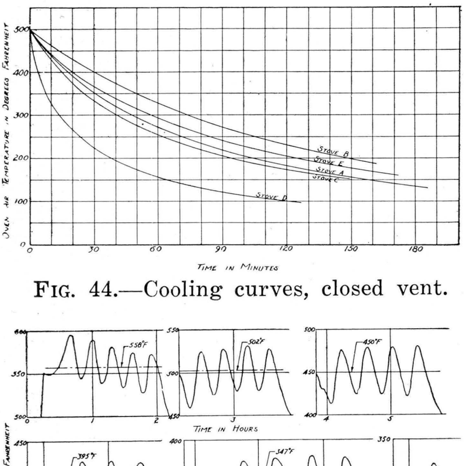

FIG. 44.—Cooling curves, closed vent.

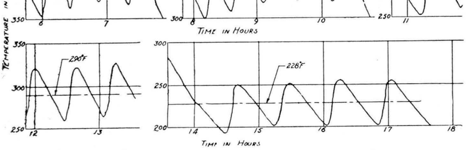

FIG. 45.—Thermostat calibration for stove E.

the opening of oven A. To show how the average temperature was determined, the variation of oven air temperature with time for oven E at 400° F. is shown in Figure 43. The cooling curves for the five ovens are shown in Figure 44. Except for stove E the results fall in the same order as the curves of heat loss per unit of area in Figure 40.[20]

From the point of view of the operation of an electric stove and the calculation of heat loss for the unsteady state, probably the most important test is the calibration of the thermostat. Owing to the extreme length of a calibration curve, it is divided into portions for illustration. Figure 45 shows the calibration curve of stove E. The calibration curves for the other stoves are similar to this curve. If each portion is joined to the preceding portion, the complete picture of the total curve is shown. The line indicating average temperature for each thermostat setting was drawn so that the area of the curve above the line was as nearly equal as possible to the area below the line. The average temperature for each thermostat setting is compiled in Table 29. To show the variation

[20] However, the cooling curves represent the transmission of heat for the unbalanced state so that the curves of heat loss per unit of area might not be expected to have the same order as the cooling curves because of the different qualities of the ovens.

TABLE 29.—*Calibration temperature vs. thermostat settings*

Thermostat setting	Average calibration temperatures					
	Stove A, original test	Stove B, original test	Stove C, original test	Stove D		Stove E, original test
				Original test	Baffle over unit	
	Degrees F.	*Degrees F.*	*Degrees F.*	*Degrees F.*	*Degrees F.*	*Degrees F.*
600	......	......	......	607	478	......
550	552	619	......	545	432	558
525	539	......	......	......	......	......
500	515	590	525	503	405	502
450	458	551	463	455	363	450
400	405	502	403	415	332	395
350	350	457	336	373	307	347
300	293	393	275	333	290	290
250	243	337	183	298	270	228
200	178	......	......	......	......	......

between calibrated temperature and thermostat setting, the differences between the two are listed in Table 30. The thermostat circuit of stove B operates on a different principle from that of the thermostats of the other ovens. When once the thermostat disconnects the units from the circuit, the units remain off. The only way that the units may be turned on again is by hand. For this reason it is hard to compare this oven with the others. This method is called

TABLE 30.—*Difference between calibration temperature and thermostat setting*

Thermostat setting	Temperature difference in degrees Fahrenheit					
	Stove A, original test	Stove B, original test	Stove C, original test	Stove D		Stove E, original test
				Original test	Baffle over unit	
600	....	....	....	+ 7	−122	....
550	+ 2	+ 69	....	− 5	−118	+ 8
525	+14	....	....	....	....	....
500	+15	+ 90	+25	+ 3	− 95	+ 2
450	+ 8	+101	+13	+ 5	− 87	0
400	+ 5	+102	+ 3	+15	− 68	− 5
350	0	+107	−14	+23	− 43	− 3
300	− 7	+ 93	−25	+33	− 10	−10
250	− 7	+ 87	−67	+48	+ 20	−22
200	−22	....	....	....	....	....

the "Dutch Oven Method." In order to obtain sufficient energy for cooking it is necessary to preheat to higher temperatures than indicated on the thermostat. This accounts for the great difference between calibration temperatures and thermostat settings. The best calibrations were obtained for stoves A and E. The temperatures of oven C are much too high at high temperatures and much too low at low temperatures. If the operator relies upon the thermostat settings as an indication of proper oven temperatures, oven D calibrates much too high at low temperatures. The effect of placing a baffle over the unit in oven D was observed and the results are shown in the column headed "baffle over unit." Temperatures at 250° and 300° F. were brought closer to the temperatures indicated by the thermostat, but above 300° F. the oven-air temperatures were much too low.

The sensitivities of the thermostats, that is, the maximum temperature differences through which the thermostat operated, are listed in Table 31. At 350°, 300°, and 250° F., the oven temperature remained almost constant at times for stove D. Occasionally humps were produced and these have been indicated by listing the sensitivities as varying between certain values.

TABLE 31.—*Sensitivity of thermostat*

Thermostat setting	Temperature range through which thermostat operates			
	Stove A, original test	Stove C, original test	Stove D, original test	Stove E, original test
Degrees F.	*Degrees F.*	*Degrees F.*	*Degrees F.*	*Degrees F.*
600	....	....	22	....
550	56	....	22	46
525	56	....	....	....
500	59	52	26	52.5
450	59	56	23	58
400	61	57	22	61
350	61	62	15-0-26	66
300	62	56	15-6	64
250	63	63	2-0	54
200	60	....	....	....

An important table is No. 32, which shows the average time per cycle and the time and percentage of time that the lower unit was on per cycle. An exception should be made in the 400°, 350° and 300° F. columns for stove D. The values given here are not per cycle, but on an hourly basis. This was necessary, for cycles were not always produced at these thermostat settings and those that were produced were very irregular. It is interesting to note the effect that a cold body in the oven had upon the data in Table 32. Two fruit cakes having a combined weight of about 5 pounds were baked in the oven of stove E with the thermostat set at 275° F. The total baking period was 4 hours and 15 minutes, including the heating of the oven. The cakes were placed in the cold oven. The oven was heated to 330° F. before going OFF and the thermostat operated through 5 complete cycles and one partial cycle. The time per cycle increased from 32 minutes at the beginning to 41 minutes at the end. The average percentage of time ON was 18.67. The average oven temperature increased from 245° to 255° F. It will be observed that these temperatures agree well with the calibration data in Table 29, where it is shown that an oven temperature of 250° F. required that the thermostat be set at 275° F. The

TABLE 32.—*Total time per cycle and time unit was on per cycle*

Stove	Distribution of time	Time per cycle in minutes for thermostat settings							
		600° F.	550° F.	500° F.	450° F.	400° F.	350° F.	300° F.	250° F.
A	Total *(min.)*	......	22.91	22.22	24.25	25.00	27.50	33.22	41.75
	On *(min.)*	......	10.33	9.16	8.06	6.94	6.08	5.44	4.84
	On *(p. ct.)*	......	45.0	43.0	33.2	27.8	22.0	16.4	11.6
C	Total *(min.)*	......	......	15.00	15.00	17.00	21.00	25.00	52.50
	On *(min.)*	......	......	6.45	5.41	5.07	4.60	4.45	4.14
	On *(p. ct.)*	......	......	43.0	36.0	29.8	21.9	17.8	7.9
D	Total *(min.)*	3.73	4.22	5.15	4.78	60.00	60.00	60.00	....
	On *(min.)*	2.11	1.86	1.86	1.59	15.00	10.00	9.19	....
	On *(p. ct.)*	56.5	44.0	36.2	33.2	25.0	16.7	15.3	....
E	Total *(min.)*	......	18.87	20.33	23.67	27.00	31.00	38.25	46.75
	On *(min.)*	......	8.88	8.28	7.85	7.26	7.18	6.20	5.13
	On *(p. ct.)*	......	47.0	40.7	33.1	26.9	23.2	16.2	11.0

time per cycle falls approximately between the columns 350° and 300° F. in Table 32, as likewise does the percentage of time the unit was on. Such a result would be expected when an actual baking is performed.

The temperature distribution of the oven air at 300°, 400°, and 500° F. is given in Table 33. From the practical point of view the oven temperature may be considered as uniform.

From the data in Table 32 and the preheating data in Table 34 obtained from the calibration curves, it is possible to calculate the energy required by each oven during a certain period of time. The power inputs in watts for both upper and lower units and for the lower unit only are given in Table 35. For

TABLE 33.—*Temperature distribution in ovens*

Location of couples	Stove A			Stove B, Closed vent			Stove B, Open vent			Stove C, Closed vent		
	500	400	300	500	400	300	500	400	300	500	400	300
	° F.	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*
1	499	398	298	480	391	299	483	404	298	485	391	300
2	494	400	300	505	402	291	502	387	290	482	389	299
3	497	400	302	507	401	300	505	400	301	498	400	305
4	473	383	296	496	400	306	500	416	306	491	396	302
5	511	407	311	535	412	296	510	395	295	467	378	288
6	482	387	291	490	394	296	491	404	294	493	394	300
7	489	393	296	502	401	297	497	395	293	489	392	299
8	507	405	303	502	404	299	502	402	298	508	404	308
9	496	399	302	493	397	303	497	408	302	517	410	309
10	512	422	316	515	407	294	510	395	294	488	394	300
11	486	388	289	486	393	305	488	410	301	490	392	298
12	479	387	293	514	408	288	494	390	286	489	391	298
13	515	410	303	510	409	304	507	408	300	509	404	305
14	485	389	301	490	396	305	498	412	305	517	413	310
15	523	418	307	523	412	297	517	396	294	493	394	300
Average	498	398	302	499	401	299	500	400	298	499	399	302

Upper plane: 1, right front; 2, left front; 3, center; 4, right back; 5, left back. Mid-plane: 6, right front; 7, left front; 8, center; 9, right back; 10, left back. Lower plane: 11, right front; 12, left front; 13, center; 14, right back; 15, left back.

TABLE 33.—*Temperature distribution in ovens*—(*Continued*)

Location of couples	Stove C Open vent			Stove D				Stove E Closed vent			Stove E Open vent		
	500	400	300	600	500	400	300	500	400	300	500	400	300
	° F.	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*
1	485	391	292	594	494	396	305	493	384	291	498	399	294
2	482	388	290	506	444	392	298	481	384	292	484	388	289
3	509	400	299	616	510	407	306	502	399	304	499	400	298
4	487	393	294	601	500	400	......	479	384	294	479	390	294
5	494	393	292	600	500	398	303	514	406	310	503	404	307
6	490	392	295	598	496	396	302	489	392	296	493	396	296
7	490	393	293	595	493	393	298	495	395	297	497	393	295
8	508	406	306	619	513	410	311	507	402	303	503	404	300
9	502	404	307	605	501	401	304	491	393	299	488	395	295
10	508	405	308	600	499	398	303	519	412	321	510	411	317
11	488	390	294	599	495	395	297	487	388	294	483	388	289
12	490	393	294	602	495	394	298	492	388	294	492	391	293
13	507	404	301	625	512	406	305	516	406	304	509	410	301
14	506	405	309	600	497	396	297	482	386	295	476	387	289
15	513	407	309	601	498	395	297	517	415	314	507	420	318
Average	499	399	300	......	500	399	303	499	398	302	496	399	301

example, the total energy required to preheat and maintain oven temperatures for thermostat settings 300°, 400°, and 500° F. when the thermostat operated for one-hour and two-hour periods, exclusive of the preheat time, is listed in Table

TABLE 34.—*Time required to preheat ovens using both units—data taken from calibration tests*

Stoves	Thermostat settings 550° F.	500° F.	450° F.	400° F.	350° F.	300° F.	250° F.
	Min.	*Min.*	*Min.*	*Min.*	*Min.*	*Min.*	*Min.*
A	20.0	17.0	14.5	12.0	10.0	8.3	7.0
B	28.8	21.4	19.5	17.3	15.5	13.2	11.2
C	......	17.5	12.6	10.7	8.8	6.6	4.3
D	13.5	10.5	8.3	7.6	6.0	5.1	4.5
E	17.5	14.3	12.2	10.3	9.1	8.0	6.0

36. The results were calculated in the following manner. The number of times that the unit was on during the one-hour and two-hour periods was determined from Table 32. By multiplying the number of times ON by the average time per cycle and the watts input for the lower unit, and adding to this the energy required to preheat, which is the product of the time listed in Table 34 and the watts input for both units, the total energy was obtained. The results in Table 36 show that for a one-hour period of thermostat operation oven D was the most economical to operate.

TABLE 35.—*Power input in watts for oven units*

Stove	Input of oven units: Both units on HIGH	Lower unit on HIGH
	Watts	*Watts*
A	2,916	1,530
B	3,360	1,734
C	2,883	1,494
D	1,770	1,770
E	3,063	1,602

TABLE 36.—*Total energy required to preheat and maintain oven temperatures for thermostat settings of 300°, 400°, and 500° F.*

Stove	Operation of thermostat for one hour			Operation of thermostat for two hours		
	300° F.	400° F.	500° F.	300° F.	400° F.	500° F.
	Watt-hrs.	*Watt-hrs.*	*Watt-hrs.*	*Watt-hrs.*	*Watt-hrs.*	*Watt-hrs.*
A	680	1,114	1,527	958	1,468	2,227
B	739	969	1,198	739	969	1,198
C	649	1,019	1,483	871	1,422	2,125
D	421	667	968	692	1,109	1,617
E	688	1,117	1,392	994	1,505	2,055

For the two-hour period oven B was the most economical. For all periods greater than two hours oven B definitely used the least energy, provided the oven did not have to be turned on again during the baking period. However, since most baking operations are completed in less than 2½ hours it is impractical to compare the ovens for long periods.

CONCLUSIONS

The conclusions to be drawn from the results of the oven tests are as follows:

1. In preheating to the same oven-air temperature, oven D required less than half as much energy as ovens A, C, and E, and less than one-third as much as oven B. Rated according to the least time and energy necessary to preheat to the same oven-air temperature, the ranking was D, C, E, A, and B.

2. Oven B had the least total heat loss and oven D the greatest. According to ascending heat loss, the ovens ranked B, A, C, E, and D.

3. If the total heat loss is divided by the inside area of the oven, ovens C and E change places in ranking. Rated according to the heat loss per square foot, the ranking is oven B, A, E, C, and D.

4. The heat loss when the oven door was opened was almost the same for ovens B, C, and D for temperatures up to 400° F., with oven A next in order and oven E losing the most heat. For oven air temperatures above 400° F. the ovens should be ranked C, D, B, A, and E.

5. The cooling curves indicate that the heat loss was much greater at high temperatures than at low temperatures. Because of its small thermal mass, oven D cooled rapidly. In the order of slowest cooling, the ranking was B, E, A, C, and D.

6. In energy required to preheat and to maintain at a desired temperature for one hour of thermostat operation, oven

D was the most economical despite its high heat loss. For periods of thermostat operation greater than one hour, oven B was the most economical. The remaining ovens ranked C, A, and E for all periods of thermostat operation, oven E requiring the most energy.

7. Because of the principle of operation, the thermostat on oven B should not be compared with the other thermostats. The calibration of the thermostat of oven E was the most accurate, with that of oven A next in order. The calibration of the thermostat of oven C was too high at 450° and 500° F. and much too low at 300° and 250° F. The calibration of the thermostat of oven D was fairly accurate at 450°, 500°, 550°, and 600° F. The average temperatures were much too high at 400°, 350°, 300°, and 250° F. Oven D had the most sensitive thermostat.

8. The temperature of the oven air at various locations was sufficiently uniform for practical purposes.

[2½M]